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AN EVALUATION OF THE EFFECT OF NORTH CAROLINA'S 1992-93 OXYGENATED FUEL PROGRAM ON AMBIENT CARBON MONOXIDE LEVELS IN URBAN AREAS

by

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ABSTRACT

Carbon monoxide is a by-product of the incomplete combustion of fuels, including motor vehicle exhaust emissions. Reduction of carbon monoxide emissions is one of the goals of the Clean Air Act, reauthorized in 1990. Amendments to the revised Act give US EPA the authority to mandate that states sell only oxygenated fuel during the months of November through February (CO season) in areas designated non-attainment for carbon monoxide.

In November 1991, three North Carolina counties were designated non-attainment because recorded readings of carbon monoxide at ambient monitoring sites within these counties showed that the 8-hour standard had been exceeded during the 1988-89 winter season. As a result, these three counties plus eight neighboring counties were mandated by US EPA to sell only oxygenated fuel during the 1992-93 CO season. Thus the focus of this study was to evaluate whether the use of oxygenated fuel resulted in decreased ambient carbon monoxide levels in the major metropolitan areas located within these non-attainment counties.

Using hourly carbon monoxide readings from air quality monitoring stations within the study area, exploratory statistical methods indicated that the data were not normally distributed and that nonparametric techniques should be employed for the analyses. Accordingly, the carbon monoxide hourly data were aggregated by daily medians and maximums for use with various nonparametric descriptive methods, including box plots.

The first group of analyses investigated the possibility that ambient carbon monoxide levels during the 1992-93 CO season were lower than in the three previous CO seasons at individual monitoring sites. The results of these analyses indicated that ambient carbon monoxide concentrations at most individual monitoring sites, both within and outside the oxygenated fuel areas, were not significantly different when comparing statistics from the 1992-93 CO season with those from the three previous CO seasons.

However, several individual sites did exhibit slightly lower levels of carbon monoxide for selected months within the 1992-93 CO season as compared to the same months within the previous CO seasons. Therefore, the use of oxygenated fuel may have been effective in decreasing ambient carbon monoxide levels at certain locations. For some sites, though, ambient carbon monoxide levels went up slightly for selected months of the 1992-93 CO season when compared to the same months within previous CO seasons.

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The second group of analyses examined whether lower ambient carbon monoxide levels were found at sites located within oxygenated fuel areas as opposed to sites located in non-oxygenated fuel areas during the same CO seasons. These analyses showed that there did not appear to be a statistically significant difference in ambient carbon monoxide levels at sites located within oxygenated fuel areas as compared to sites located outside these areas during similar time periods.

Therefore, this study concludes that it cannot be demonstrated that the use of oxygenated fuel in North Carolina during the months of November through February 1992-93 resulted in an overall statistically significant reduction of ambient carbon monoxide levels within counties designated non-attainment, but that small, localized improvements may have been realized.

INTRODUCTION

Carbon monoxide is a by-product of the incomplete combustion of fuels. While many human activities contribute to the release of carbon monoxide to the atmosphere, the primary sources are automobile exhaust emissions and the heating of human-inhabited structures. Hence, elevated levels of ambient carbon monoxide are usually associated with urban areas because of the high density of industrial and residential development and the corresponding increase in automobile traffic.

Certain meteorological events can contribute to high concentrations of ambient carbon monoxide, the most prevalent being temperature inversions. Atmospheric conditions become very stable during temperature inversions, with minimal wind flow and vertical mixing. Under these conditions, cooler, polluted air gets trapped beneath warmer, cleaner air resulting in the poor dispersion of all air pollutants, including carbon monoxide. Temperature inversions can occur as daily events, dependent on the microclimate of an area, or as events whose frequency is based on large-scale seasonal meteorological patterns. Even the normal daily heating and cooling patterns of an urban area can affect the spatial and temporal dispersion of localized concentrations of carbon monoxide.

The health effects of increased ambient carbon monoxide levels have been well documented. Carbon monoxide can accelerate the onset of fatigue during strenuous work or exercise and can impair the ability to perform complicated tasks. Especially of concern is the effect of increased carbon monoxide levels on several risk groups: people with coronary artery disease or angina problems; the elderly; those having respiratory diseases, such as asthma or emphysema; and persons having certain hematological diseases, such as anemia.

In 1990, Congress passed a set of amendments to the Clean Air Act. Title II of the reauthorized Act deals with mobile sources and contains a variety of provisions to reduce carbon monoxide emissions. One of these provisions authorizes the United States Environmental Protection Agency (US EPA) to mandate that states participate in a wintertime oxygenated fuel program within areas designated non-attainment for carbon monoxide (oxygenated fuel is very similar to normal gasoline except that it contains an extra additive, termed an oxygenate, that is reported to reduce tailpipe emissions of carbon monoxide by 25 percent). The oxygenated fuel program is set up to be in effect during the winter months of November through February because gasoline combustion is less efficient at lower temperatures resulting in increased emissions, and because the colder, heavier winter air causes pollutants to stay closer to ground level. For program purposes, US EPA has designated this time period as the "CO season".

In November of 1991, three North Carolina counties, Forsyth, Durham, and Wake, were designated non-attainment for carbon monoxide. This occurred because ambient carbon monoxide levels recorded at air quality monitoring stations sited within urban areas in these counties violated the 9 parts per million (ppm) carbon monoxide standard during the 1988-89 winter season (the 9 ppm standard is for non-overlapping 8-hour means and cannot be exceeded more than once per year per station). As a result of this status, these counties, and the immediate surrounding counties that contribute to their motor vehicle traffic, were mandated by the US EPA to sell only oxygenated fuel during the months of November through February in the 1992-93 winter season. The following counties were therefore required to participate in the program: Yadkin, Stokes, Forsyth, Davie, Davidson, Guilford, Randolph, Orange, Durham, Wake, and Franklin. Mecklenburg County was not required to participate in the program because its non-attainment status had been designated in earlier years and was not based upon a standards violation during the 1988-89 winter season. Both the non-attainment counties and the participant counties are illustrated in Appendix A.1.

ANALYTICAL FRAMEWORK

To evaluate whether the oxygenated fuel program had a significant effect on reducing ambient carbon monoxide levels in the selected urban areas, carbon monoxide data were retrieved from US EPA's Aerometric Information Retrieval System (AIRS) database for analysis. AIRS contains carbon monoxide data collected at various urban locations across the state by the Division of Environmental Management's Air Quality Section, a regulatory agency within North Carolina's Department of Environment, Health, and Natural Resources. Review of the period of record for all current carbon monoxide sampling sites verified a continuous record back through 1989 for all the sites except for the Greensboro location, which had a period of record back to 1990.

In designing the analytical framework, the first step was to decide what carbon monoxide data in AIRS were to be used for analysis. One hour and running 8-hour means are the most common carbon monoxide data retrieved from AIRS. This is because these statistics reflect the regulatory standards for carbon monoxide. Even though North Carolina's non-attainment designation in 1991 was a result of violations of the carbon monoxide standard for running 8-hour means, it was reasoned that the one hour data offered a better resolution for analytical purposes. Evaluating whether the oxygenated fuel program had an effect on ambient carbon monoxide levels is not necessarily the same as evaluating whether the program had an effect on meeting a certain standard. Even so, the 35 ppm carbon monoxide one-hour standard (not to be exceeded more than once per year per station) was never violated during the period of record examined for the stations used in this analysis.

Monitoring station data were divided into two groups: data collected in urban areas where the oxygenated fuel program was in effect (Raleigh, Durham, Greensboro, and Winston-Salem) and data collected in areas where it was not (Fayetteville and Charlotte). This was done to compare ambient carbon monoxide levels within the oxygenated fuel areas against a control. Appendix A.2 shows the location of carbon monoxide sampling sites in North Carolina. Appendix B gives a full description of the sites complete with period of record.

To establish uniformity among sites when evaluating the data, two types of monitoring locations in each metropolitan area were selected: those at or near shopping centers, and those in downtown locations (except for Fayetteville and Greensboro, both of which have only one site). Thus when comparisons of ambient carbon monoxide trends were made between metropolitan areas, only results from similar types of sites were used. Moreover, since Mecklenberg County had more than two sampling sites, not all of that county's sites were used for analysis. The sampling sites used in the analysis are illustrated in Appendix A.3 and also listed in Appendix B.

Because of the individual traffic patterns that occur at each of the sites as well as the difference in the overall atmospheric conditions in each of the metropolitan areas, it was hypothesized that comparison of ambient carbon monoxide levels over time at the same site would yield the most meaningful information of possible changes in ambient carbon monoxide levels as related to the use of oxygenated fuel.

To assist in determining if there were trends at individual sites in the participating program area because of a change to oxygenated fuel, comparisons of carbon monoxide levels were made between similar sampling sites in the oxygenated fuel areas and non-oxygenated fuel areas to see if there were corresponding trends.

EXPLORATORY DATA ANALYSIS

Exploratory analyses used data from the following stations: RAL0013, DUR0010/0012, WS0023, and CHL0032. These stations are sited at similar locations in each of the major metropolitan areas. The evaluations used several graphical methods to examine the data for temporal trends at the daily and weekly level.

Hour-to-hour daily variations in the data can be seen in the line charts found in Appendix C. These charts were developed using data from the above four sites for the 1992-93 period when the oxygenated fuel program was in effect. Each chart uses data from a different month within the period in order to diminish the site-specific effects of month-to-month variations in traffic patterns and atmospheric conditions. The graphs illustrate that all sites had a definable increase in carbon monoxide levels around 6 am-10 am when people were traveling to work or school, diminished levels during the day when people were at their places of employment, and then rising levels around 5 pm when people were returning home. Notice that the high levels of carbon monoxide generated around 5 pm hold on into the evening. This is because air patterns usually stabilize as evening approaches and thus "lock in" the high levels of carbon monoxide associated with the increase in traffic during the late afternoon and early evening hours. Starting around 10 pm, the elevated levels of carbon monoxide start to disperse due to the decrease in traffic. This dispersion continues throughout the night even though atmospheric stability does not break up until later the next morning when surface heating occurs.

The line charts of hourly data in Appendix C are additionally ordered by day of the week. This was done to see if there was any trend in hourly readings that could be attributed to certain days of the week. The line charts indicate that there appears to be no clear pattern of any one day having the highest levels of carbon monoxide; it does appear that, in general, weekday levels are higher than weekend levels.

Appendix D presents continuous time lines for each month of the 1992-93 CO season to further illustrate day the week patterns. However, Appendix D uses the median of each day's hourly readings and not the hourly readings themselves as shown in Appendix C (use of the median instead of the mean will be discussed later). While the information regarding hour-to-hour changes is lost by aggregating the data via a central tendency statistic, the picture concerning possible trends relating to days of the week becomes clearer. Again, it appears that weekday levels of ambient carbon monoxide at these sites are higher than weekend levels (Appendix D has the weekends shaded for ease in comparing weekday and weekend values).

Appendix E contains histograms of frequency distributions that were generated for the Raleigh Crabtree Valley site for November 1992 (histograms were done for all the stations selected for analyses, but only one is illustrated). Note that the distributions represent hourly data for the first day of the month and every ten days afterward. Located to the right of each histogram there is a frequency distribution of the same data, but with a logarithmic transformation. This is a common method of manipulating skewed data so it will approximately fit a normal curve. Also shown are computer generated overlays of estimated normal distributions with the same mean and standard distribution as the data used to calculate the histograms.

Appendix E demonstrates that neither the frequency distributions of the raw data nor their logarithmic transformation result in normal distribution curves. While there is no clear pattern to the distribution of data for each of the days analyzed, it appears that the data are somewhat skewed to the right, but not uniformly enough to produce a normal curve by performing a logarithmic transformation as one might do when working with lognormal distributions. This indicates that the distribution of the data that generated the curves is not a product of consistent, systematic processes.

After reviewing the frequency distributions discussed above, it was decided that parametric statistics would not be suitable for analyzing the data and that nonparametric statistics would be more appropriate. One nonparametric method that has been widely used with environmental data is the box plot. This procedure produces a visual representation of various order statistics (commonly used percentiles) as well as calculated confidence intervals about a central tendency statistic (in this case the median, or the 50th percentile). Box plots can also be used for visual hypothesis testing, yielding basically the same results as when using formal tests for multiple independent datasets, such as the Kruskal-Wallis Test. For a description on how to interpret box plots see Appendix G.

EVALUATION OF AMBIENT CARBON MONOXIDE DATA FROM THE SUBSET OF SAMPLING SITES

Use of time lines to informally detect trends in the data was extended from the previous hourly, daily, and weekly analyses to month-by-month reviews of ambient carbon monoxide levels. Appendix F contains time lines for each of the subset of stations shown in Appendix A.3. The information depicted in Appendix F is delineated by month over annual CO season, beginning in the winter of 1989. The median and maximum for each station's daily hourly readings were calculated and plotted on a line chart.

Review of the time lines for each station revealed the following observations:

- in general, there appears to be a slight decrease in median values in each succeeding year
- there is a definite overall reduction in the maximum values each succeeding year, with the greatest reduction occurring in the 1992-93 CO season

- there is a less variability in both the medians and the maximums in the 1992-93 CO season than in previous seasons

The daily medians and maximums were then used to calculate monthly box plot statistics; these plots are shown in Appendices H and I. The box plots shown within Appendix H group the daily medians and maximums of hourly carbon monoxide readings by successive months over different CO seasons whereas Appendix I shows the same data but grouped by same month over different years.

Although carbon monoxide levels change daily due to fluctuations in traffic intensity and atmospheric patterns, Appendix H indicates that there is little difference in the monthly medians over a CO season from a standpoint of confidence interval significance. For instance, there is an increase in urban traffic during the holiday shopping season and the air patterns over North Carolina do tend to get less stable as winter progresses with more mixing of air pollutants in February than in November. Apparently, neither of these phenomena is sufficient for ambient carbon monoxide levels at the individual monitoring stations to statistically differ on a monthly basis.

Examination of the box plots of daily maximums in Appendix H shows more variation in the data than the box plots of the daily medians. This is to be expected since the medians are a central tendency statistic computed from 24 hourly observations whereas the daily maximum is only one value (because central tendency statistics aggregate data, they dampen variability). However, even with this increased variability there are very few box plots with non-overlapping confidence intervals across a CO season. Thus we can conclude that the daily maximums, like the daily medians, do not significantly change on a month-to-month basis over a single CO season.

The box plots shown in Appendix I compare the data by the same months over the four CO seasons. This enables trends to be observed on an annual basis. Even though the box plots in Appendix H demonstrate that there is little month-to-month change during an individual CO season, it was considered possible that there was change, by month, on an annual basis. Close examination of Appendix I shows that while the monthly medians for the 1992-93 CO season are seldom different from corresponding months in other CO seasons (at the 95% level of confidence), some downward trend is clearly visible.

Comparative bar charts, comprised of only the monthly medians and maximums, are used in Appendix J to illustrate the relationships between stations within and outside the oxygenated fuel area. The charts are additionally grouped by sampling site type (this was discussed earlier - i.e., shopping mall sites or downtown sites). Looking at the median values (Appendices J.1 and J.2), it appears that for most stations there was a slight drop in ambient carbon monoxide levels during the 1992-93 season; note, however, the February bar chart for Raleigh 0011 where median carbon monoxide levels rose each succeeding year. The same trends hold fairly well for the maximums (Appendices J.3 and J.4), except for the month of November at all of the downtown sampling sites and for the month of January at two of the shopping mall sites.

Appendix J shows that while median values were lower overall for the downtown sampling sites as compared to the shopping mall sites (compare Appendices J.1 and J.2), the reverse was true for the maximum values (compare Appendices J.3 and J.4). This phenomena is readily apparent when re-examining the time lines shown in Appendix F; one can see that there is much more variation in the data from downtown sites. This is probably due to daily and weekly variations in the employment-related traffic patterns of downtown areas.

Finally, Appendix K summarizes the complete dataset used for this analysis. This is done by station and CO season for the years 1989 through 1993. Appendix K.1 depicts the monthly median of the daily medians of the 24 hourly readings while Appendix K.2 shows the monthly maximum of the daily maximums of the same readings.

CONCLUSIONS AND RECOMMENDATIONS

With respect to the impact of oxygenated fuel use on ambient carbon monoxide levels in urban areas, this study concludes that, overall, there is no statistically significant difference between the CO season when the oxygenated fuel program was in effect and the previous three CO seasons when it was not. However, individual station analyses indicate that modest, localized improvements may have been realized.

Even though there was a slight downward trend of ambient carbon monoxide over time at many of the sampling sites, this phenomena does not appear to be unique for only stations in the oxygenated fuel areas.

Moreover, while carbon monoxide levels varied among the sampling sites (i.e., Winston-Salem 0018 appears to have the lowest values, while Charlotte 0038 appears to have the highest), temporal trends were not that different between stations within the program area and those outside the area.

Ambient carbon monoxide concentrations have been trending downward for years in North Carolina (see Appendix L) as well as nationwide (see Appendix M). The steady improvement in decreasing carbon monoxide levels can mainly be attributed to US EPA's long-range program of increased emission controls on motor vehicles (rudimentary emission control equipment for automobiles first went into effect in the late 1960's). Consequently, motor vehicles are simply getting more fuel efficient and cleaner burning over time. As newer, cleaner burning vehicles replace older vehicles within the existing national motor vehicle fleet, there has been a decrease in the emission levels of all "tailpipe pollutants", including carbon monoxide.

It may be possible, however, that the oxygenated fuel program did have a subtle effect in reducing carbon monoxide levels. From a statistical point of view, this could best be ascertained if the program was continued for several more years. If the program was instrumental in reducing ambient carbon monoxide levels, then after several years one would see a more steeply-sloped downward trend line from 1992-93 onward (assuming that motor vehicle improvements continue at about the same rate that they have in the past).

It is recommended that future statistical analyses incorporate atmospheric data to evaluate, and possibly account for, its probable confounding factor in analyzing air quality data. Varying atmospheric conditions, especially precipitation and wind speed, make it difficult to evaluate spatial and temporal differences in air pollutant levels. For instance, there was a 30 percent increase in the number of days with precipitation at the Raleigh-Durham Airport during the 1992-93 CO season in comparison to the 1991-92 CO season. Since precipitation has a cleansing effect on air pollutants, it may be that any decrease in carbon monoxide levels that occurred in the Triangle Area during the 1992-93 CO season can be at least partially attributed to this phenomena and not the use of oxygenated fuels.

Finally, future analyses might also include health data associated with respiratory illnesses to evaluate whether carbon monoxide levels are related to the number, frequency, or severity of reported respiratory illnesses requiring medical intervention. This type of analysis could be extended to using these same health criteria in analyzing any differences in reported respiratory illness events between areas using oxygenated fuel with areas that did not.

APPENDICES

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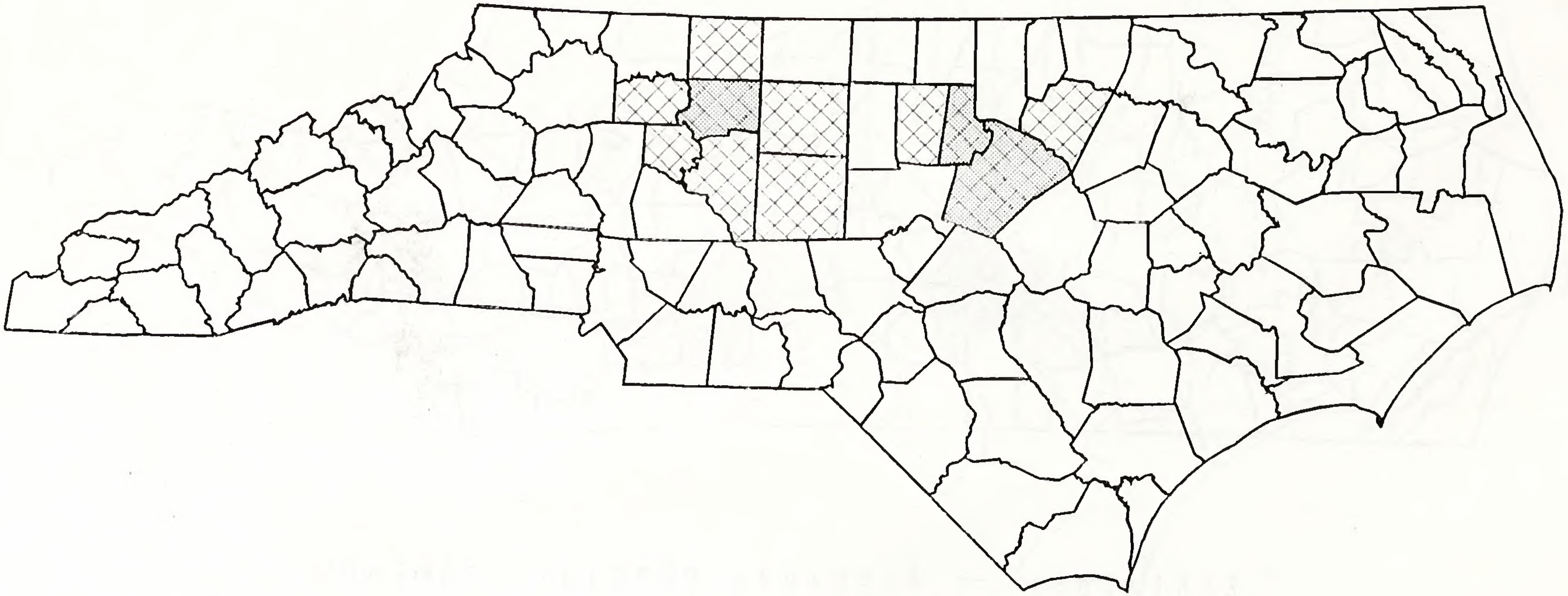
North Carolina Oxygenated Fuel Program

November through February — 1992-1993



▒ Counties Designated Non-attainment in 1991

▨ Counties Participating in Oxygenated Fuel Program

MAP PREPARED BY:
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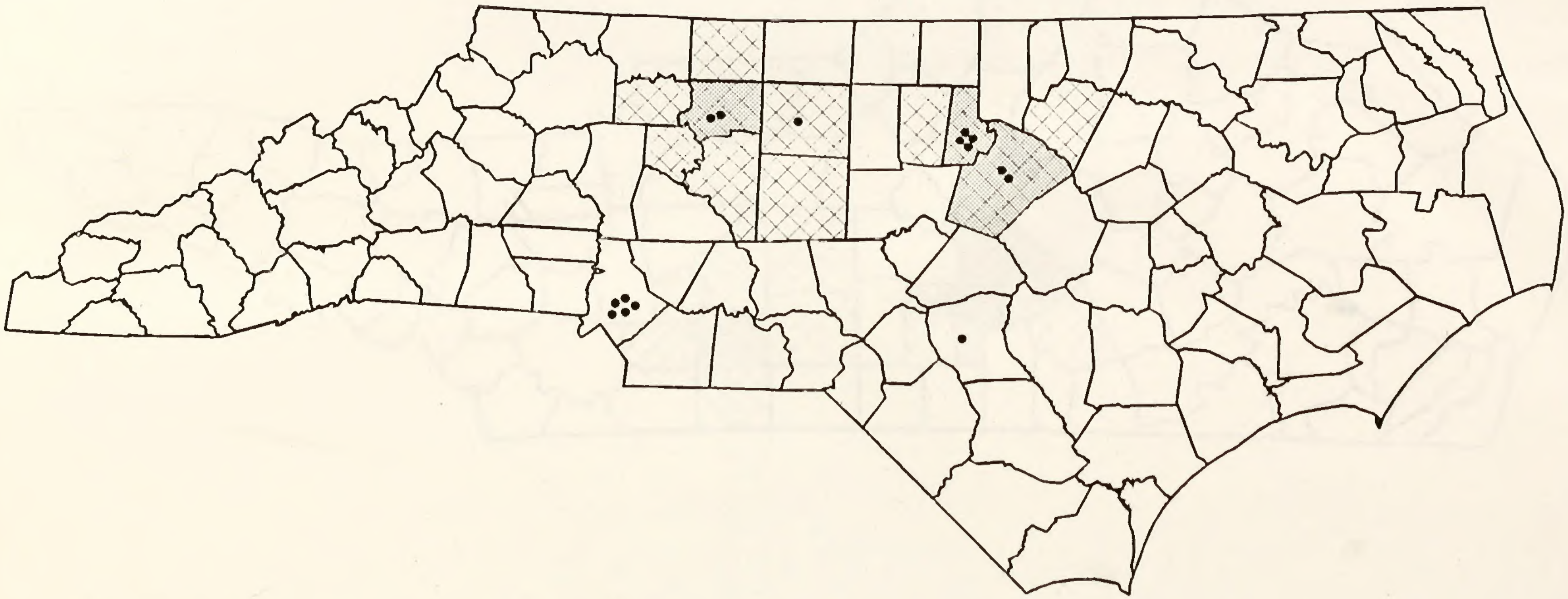
AND ENVIRONMENTAL STATISTICS
RALEIGH, NORTH CAROLINA
June, 1993

North Carolina Air Quality Monitoring System
Ambient Carbon Monoxide Sampling Sites

November through February — 1992-1993



MAP PREPARED BY:
STATE CENTER FOR HEALTH
AND ENVIRONMENTAL STATISTICS
RALEIGH, NORTH CAROLINA
June 1993

● All Sampling Sites

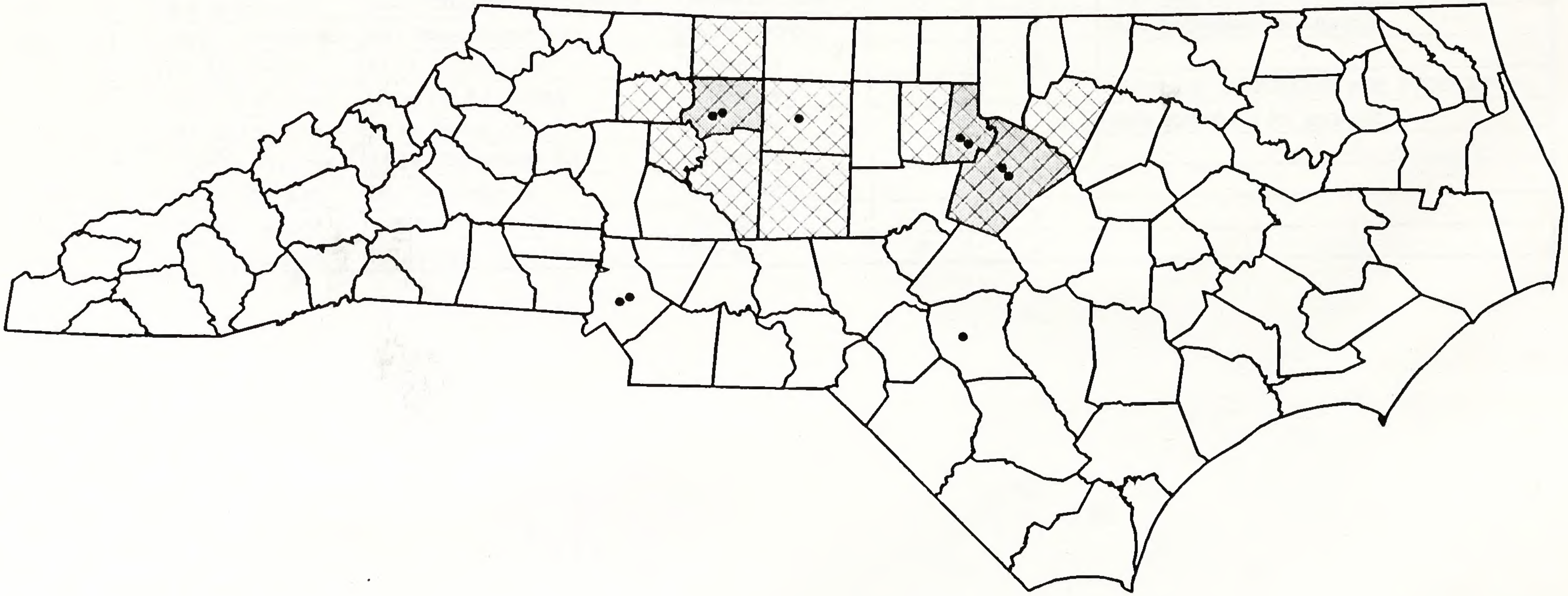
▩ Counties Designated Non-attainment in 1991

▨ Counties Participating in Oxygenated Fuel Program

North Carolina Air Quality Monitoring System

Ambient Carbon Monoxide Sampling Sites

November through February - 1989 through 1993



● Sampling Sites Used for Analysis

▩ Counties Designated Non-attainment in 1991

▨ Counties Participating in Oxygenated Fuel Program

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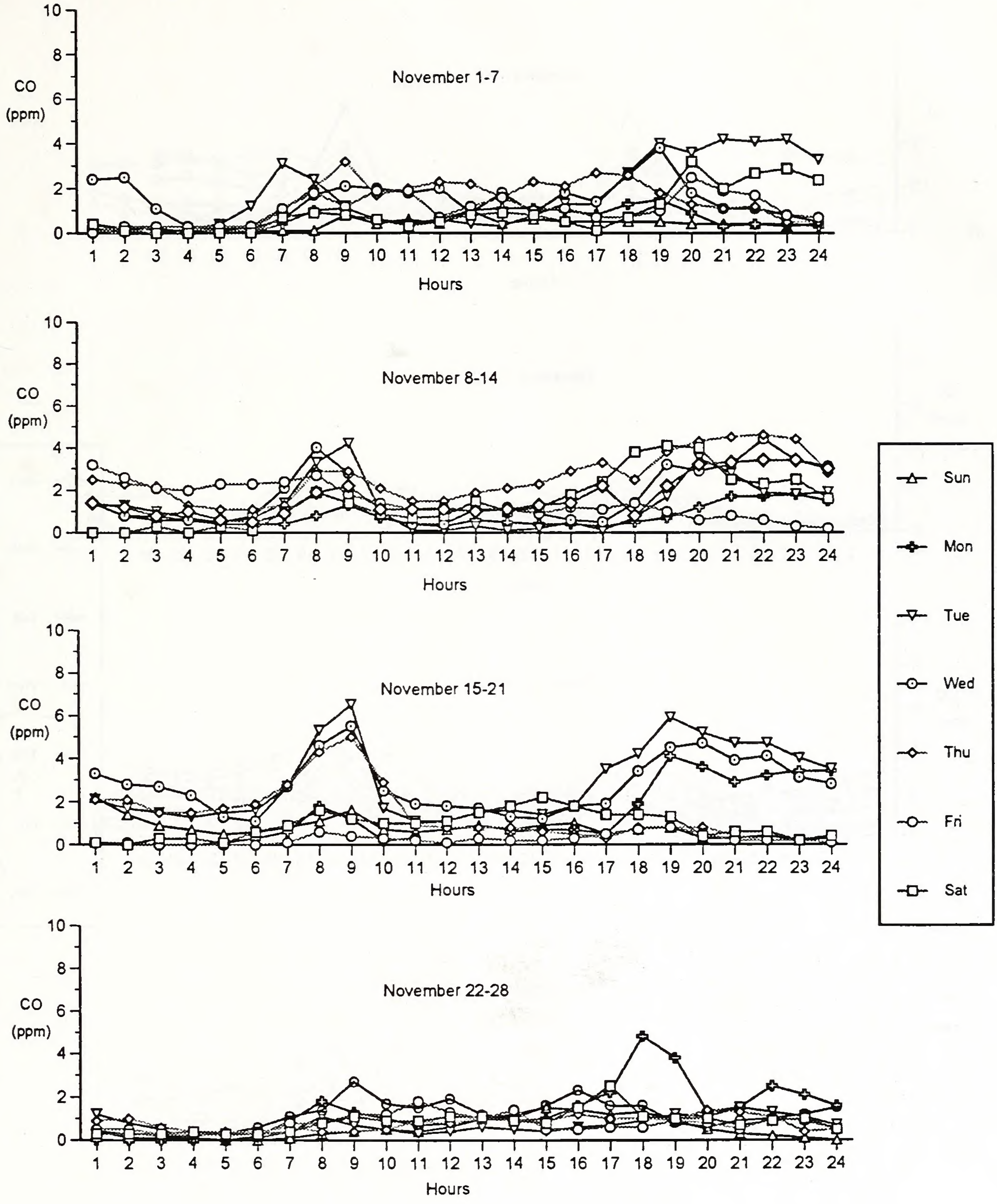
AND ENVIRONMENTAL STATISTICS
RALEIGH, NORTH CAROLINA
June 1993

Carbon Monoxide AIRS Stations

Station #	Period of Record	Address	City	Oxyfuel	Evaluated	Remarks
370510007	9/88 to Present	1705 Owen Drive	Fayetteville		X	
370630008	1/79 to 3/92	302 E. Main St	Durham*	X	X	Replaced by 370630011 on 3/30/92
370630010	11/86 to 2/93	City Park on University Dr	Durham**	X	X	Replaced by 370630012 on 2/14/93
370630011	1/92 to Present	Commerce Building	Durham*	X	X	Replaced 370630008 on 3/30/92
370630012	2/93 to Present	4001 Chapel Hill Blvd	Durham**	X	X	Replaced 370630010 on 2/14/93
370670018	1/80 to Present	201 North Main Street	Winston-Salem	X	X	
370670023	7/89 to Present	1401 Corporation Parkway	Winston-Salem	X	X	*Durham 370630008 and 370630011
370811011	12/89 to Present	401 West Wendover	Greensboro	X	X	were combined for analysis
371190032	1/77 to Present	5137 Central Ave	Charlotte		X	
371190034	10/80 to Present	Plaza Rd & Lakedell	Charlotte			**Durham 370630010 and 370630012
371190035	1/81 to Present	1330 Spring St	Charlotte			were combined for analysis
371190037	10/88 to Present	415 E. Woodlawn Rd	Charlotte			
371190038	4/89 to Present	301 N. Tryon St	Charlotte		X	
371830011	1/84 to Present	420 S. Person St	Raleigh	X	X	
371830013	1/88 to Present	EF Hutton, Hwy 70 West	Raleigh	X	X	

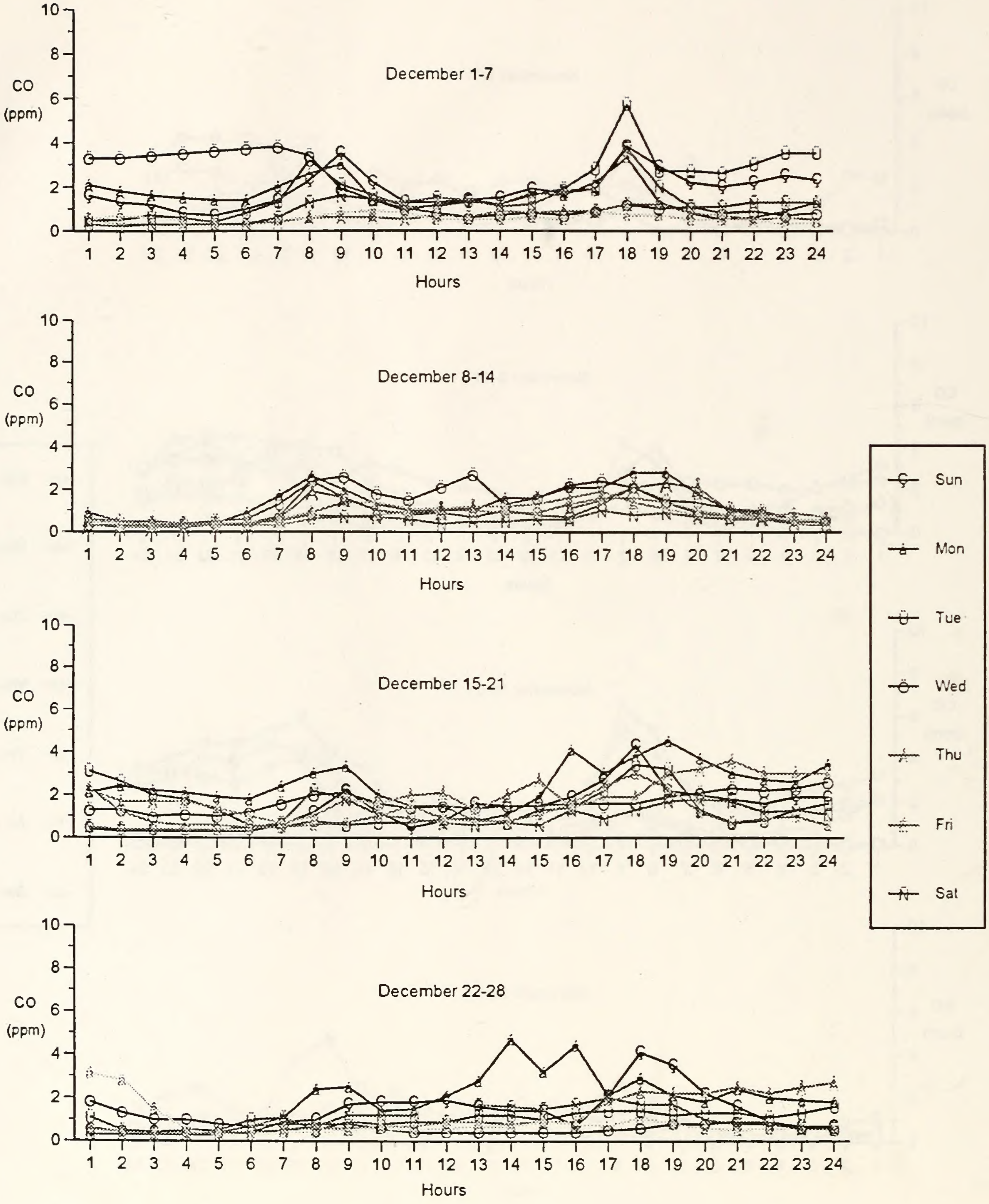
Appendix C.1



Ambient Carbon Monoxide Readings (ppm) - Station 0013 - Raleigh

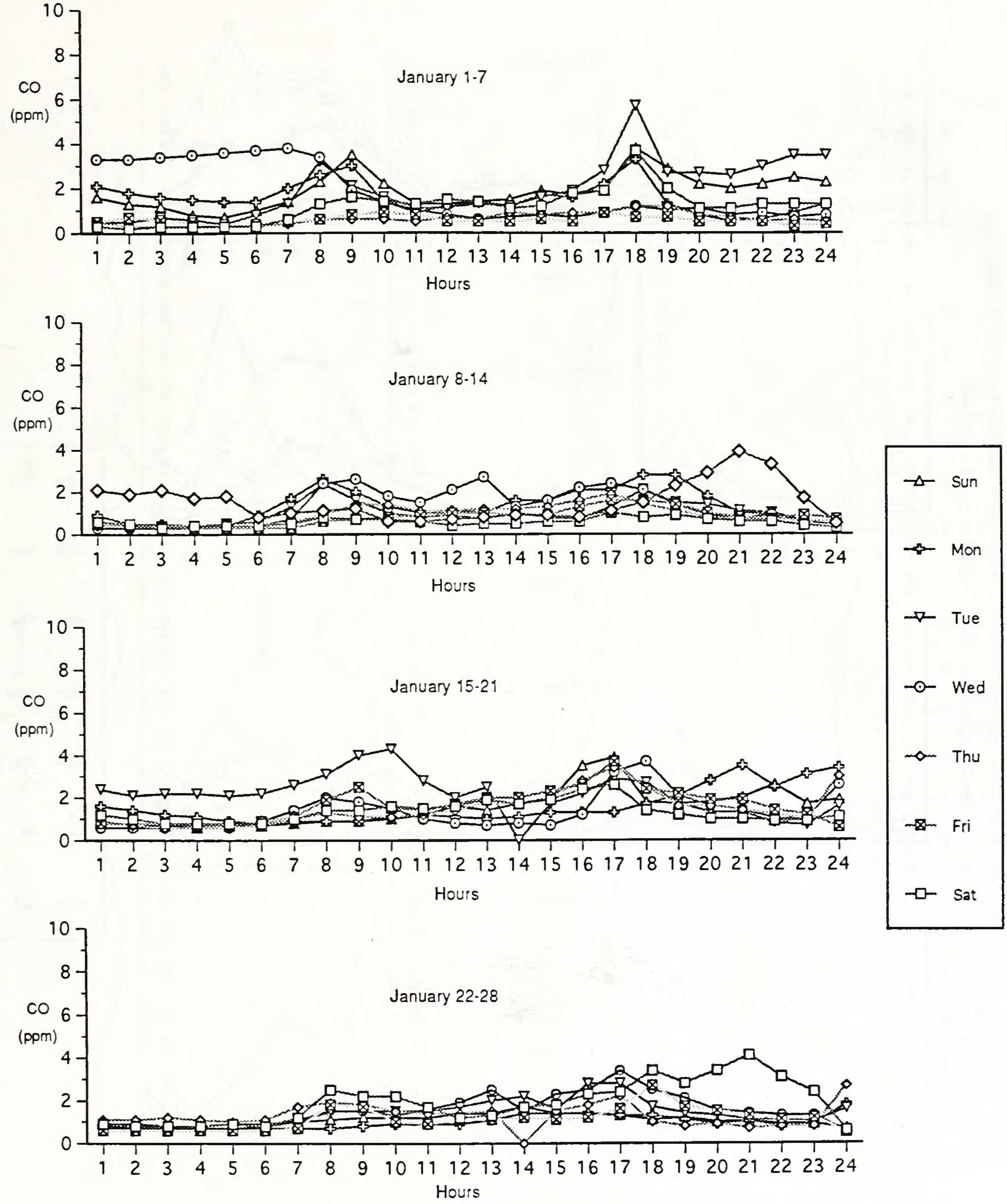
(Day of the Week Hourly Readings - By Week for First Four Weeks of November 1992)

Appendix C.2



Ambient Carbon Monoxide Readings (ppm) - Stations 0010/0012 - Durham
(Day of the Week Hourly Readings - By Week for First Four Weeks of December 1992)

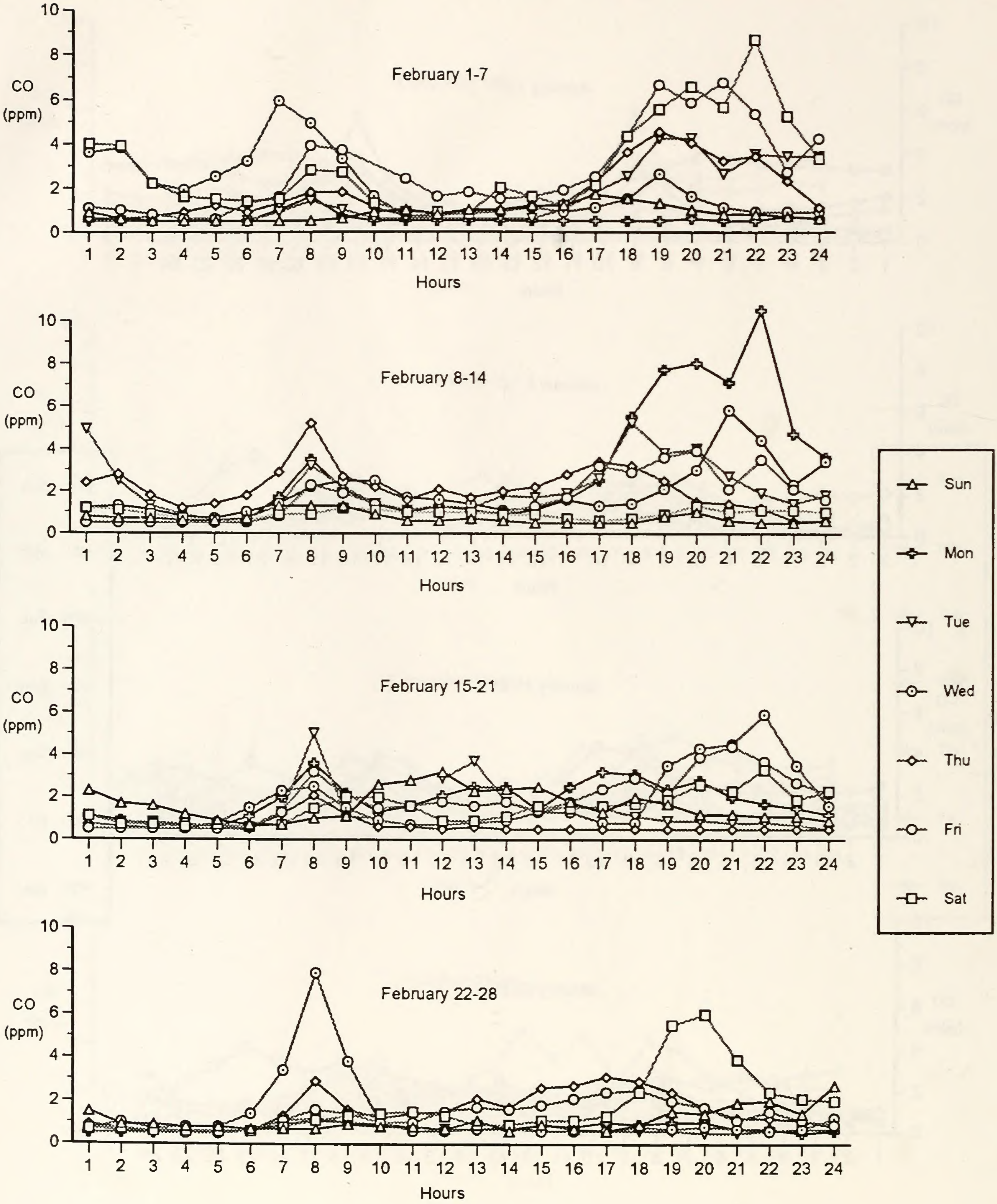
Appendix C.3



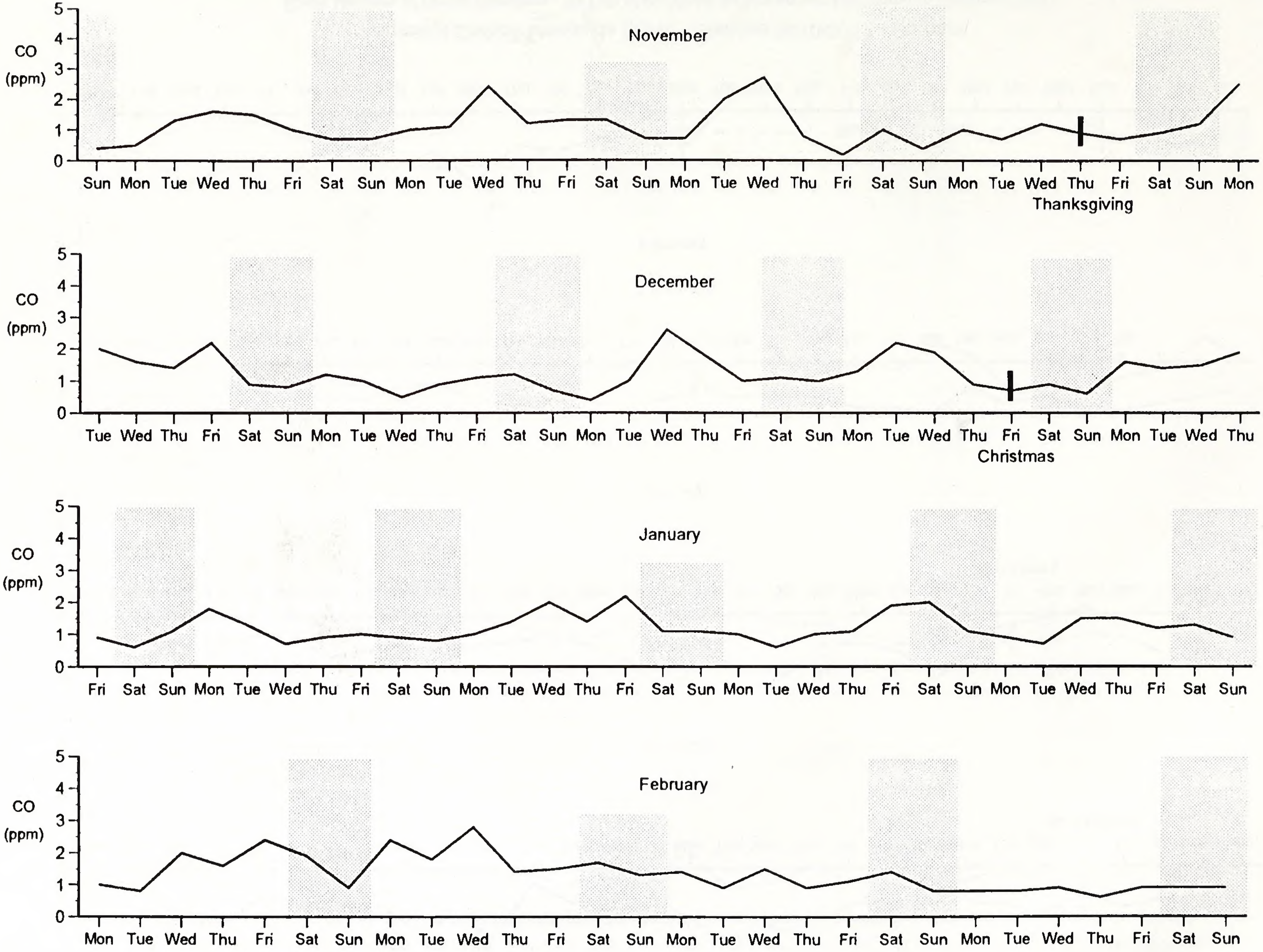
Ambient Carbon Monoxide Readings (ppm) - Station 0023 - Winston-Salem

(Day of the Week Hourly Readings - By Week for First Four Weeks of January 1993)

Appendix C.4

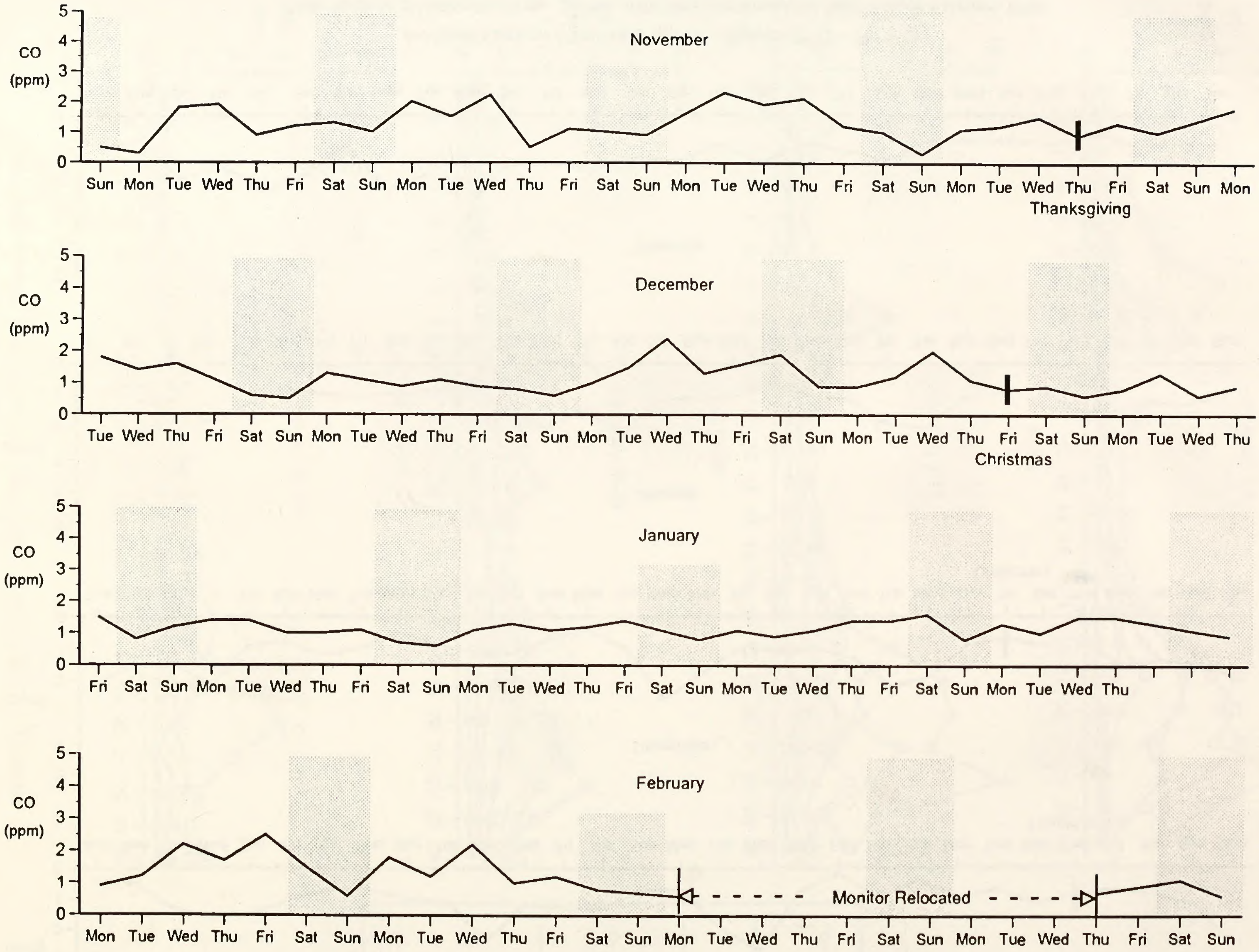


Ambient Carbon Monoxide Readings (ppm) - Station 0032 - Charlotte
(Day of the Week Hourly Readings - By Week for First Four Weeks of February 1993)



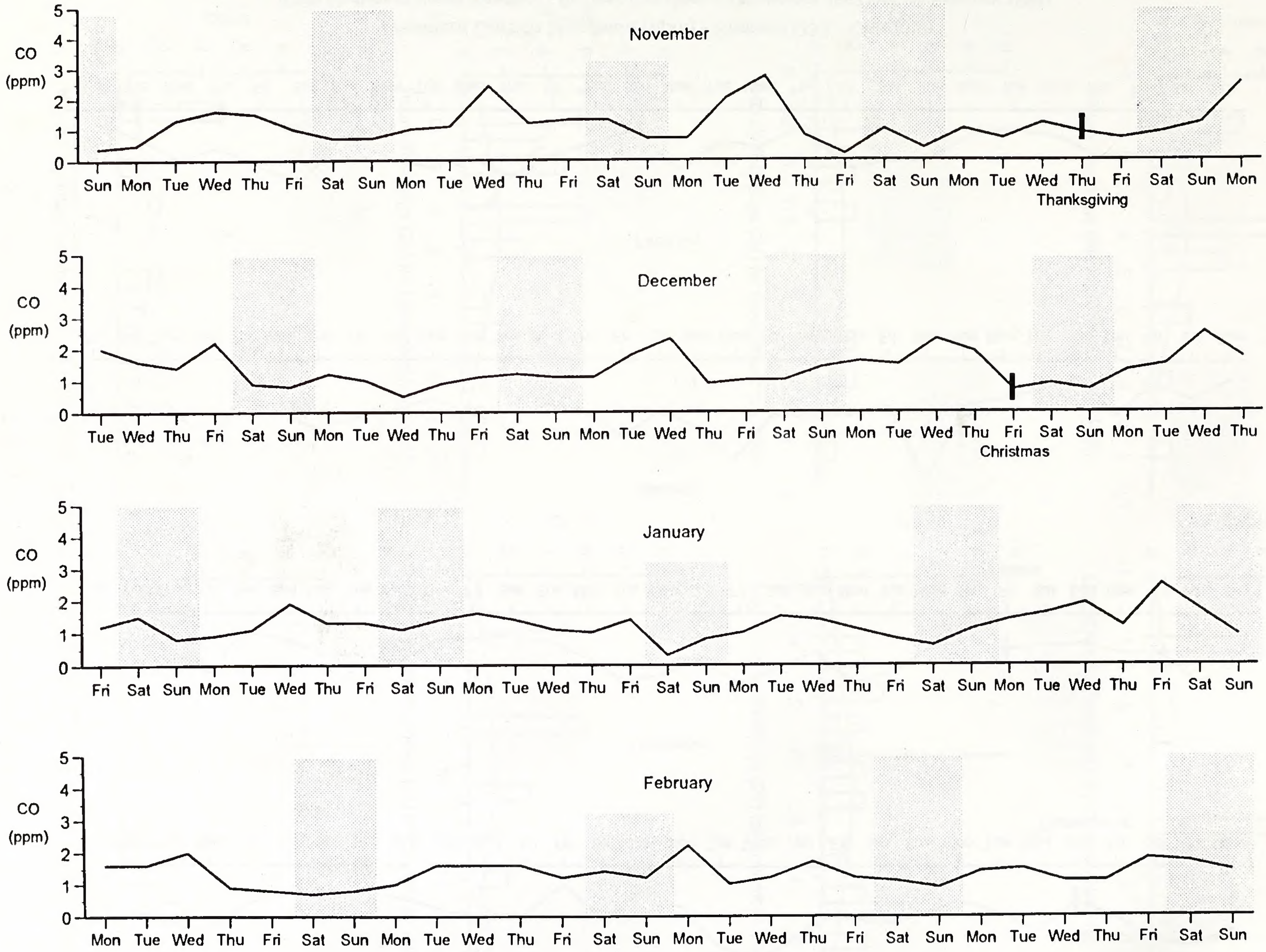
Ambient Carbon Monoxide (ppm) - Station 0013 - Raleigh

(Daily Medians of Hourly Readings - By Day of the Week for November 1992 through February 1993)



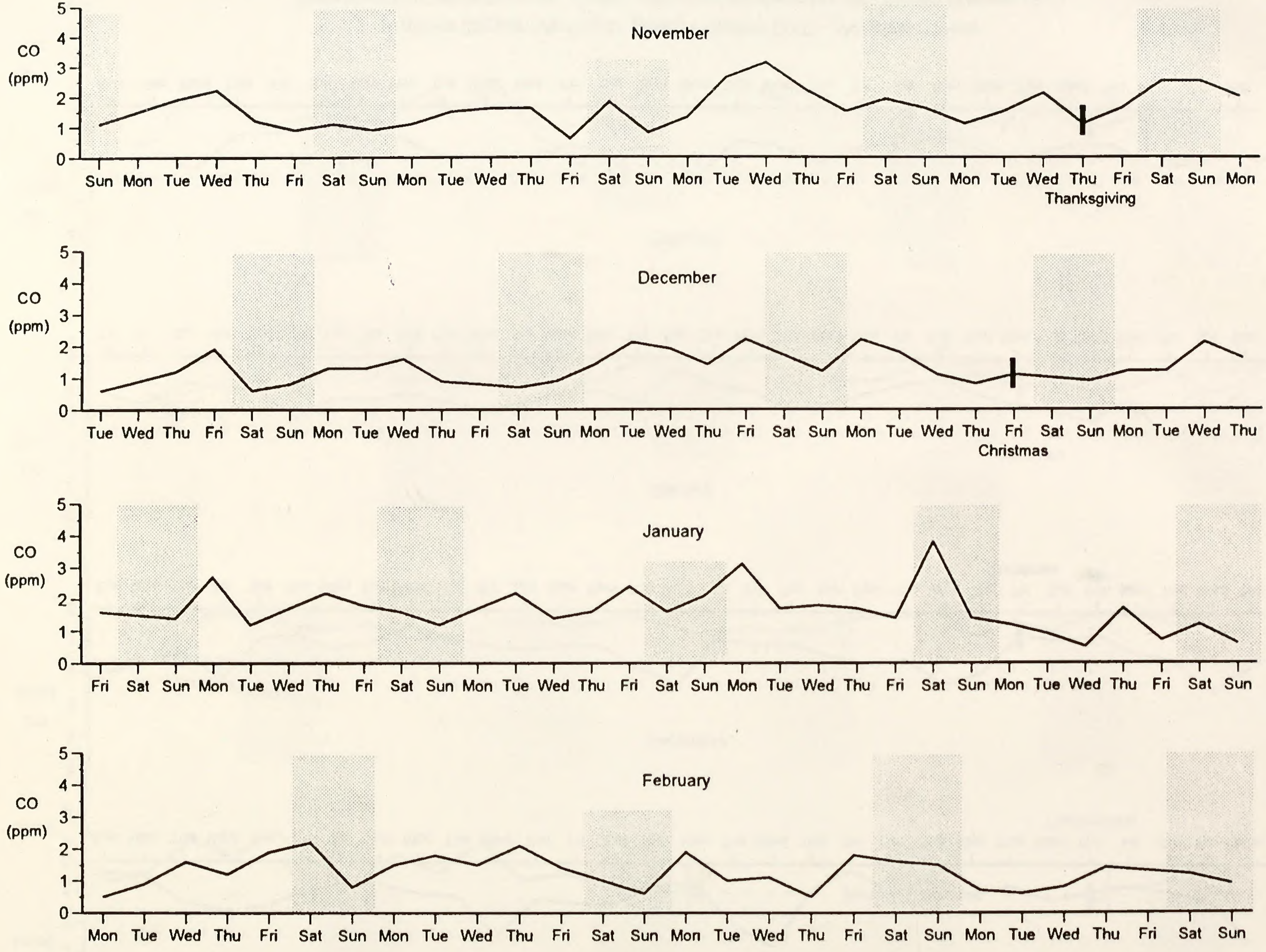
Ambient Carbon Monoxide (ppm) - Stations 0010/0012 - Durham

(Daily Medians of Hourly Readings - By Day of the Week for November 1992 through February 1993)



Ambient Carbon Monoxide (ppm) - Station 0023 - Winston-Salem

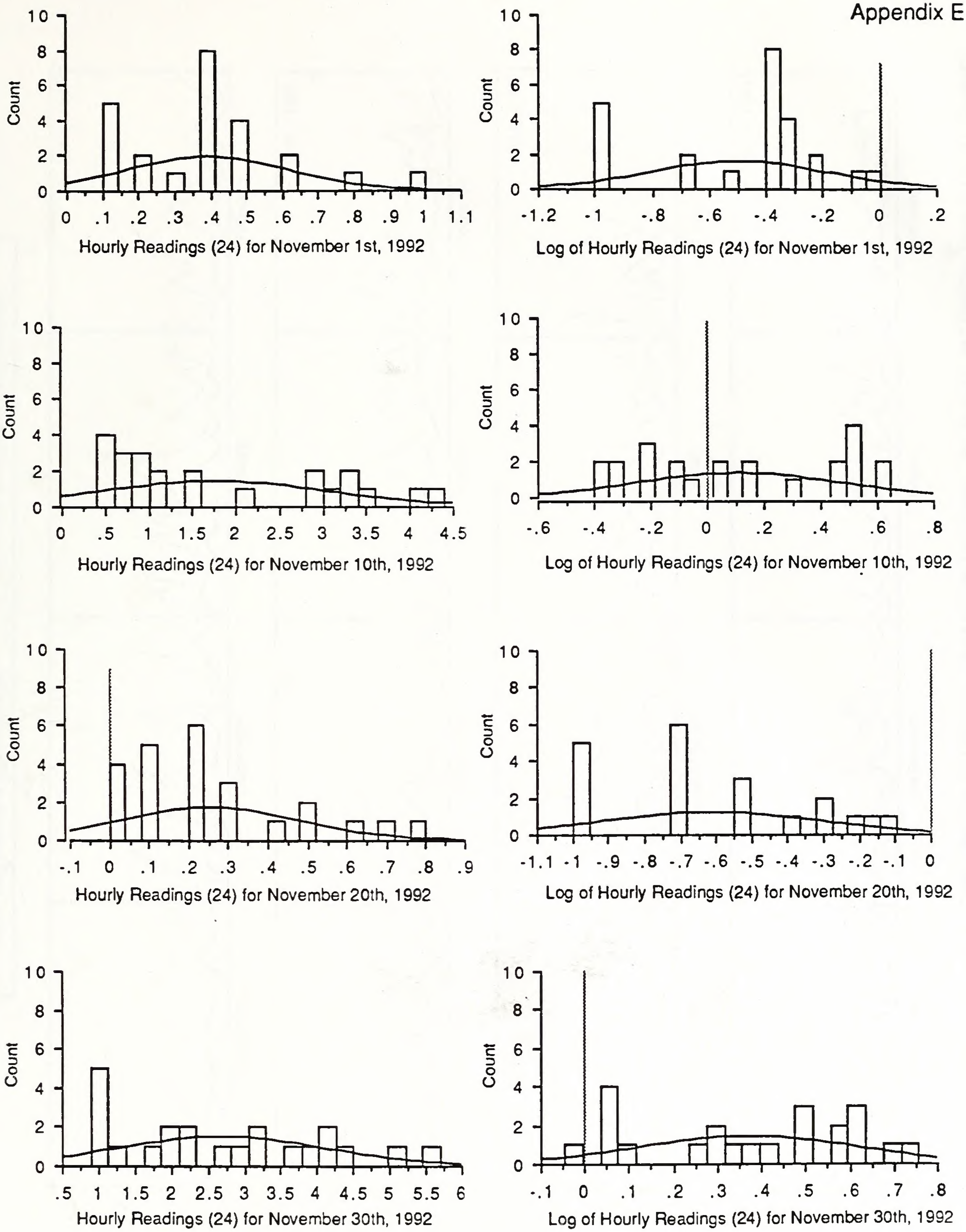
(Daily Medians of Hourly Readings - By Day of the Week for November 1992 through February 1993)



Ambient Carbon Monoxide (ppm) - Station 0032 - Charlotte

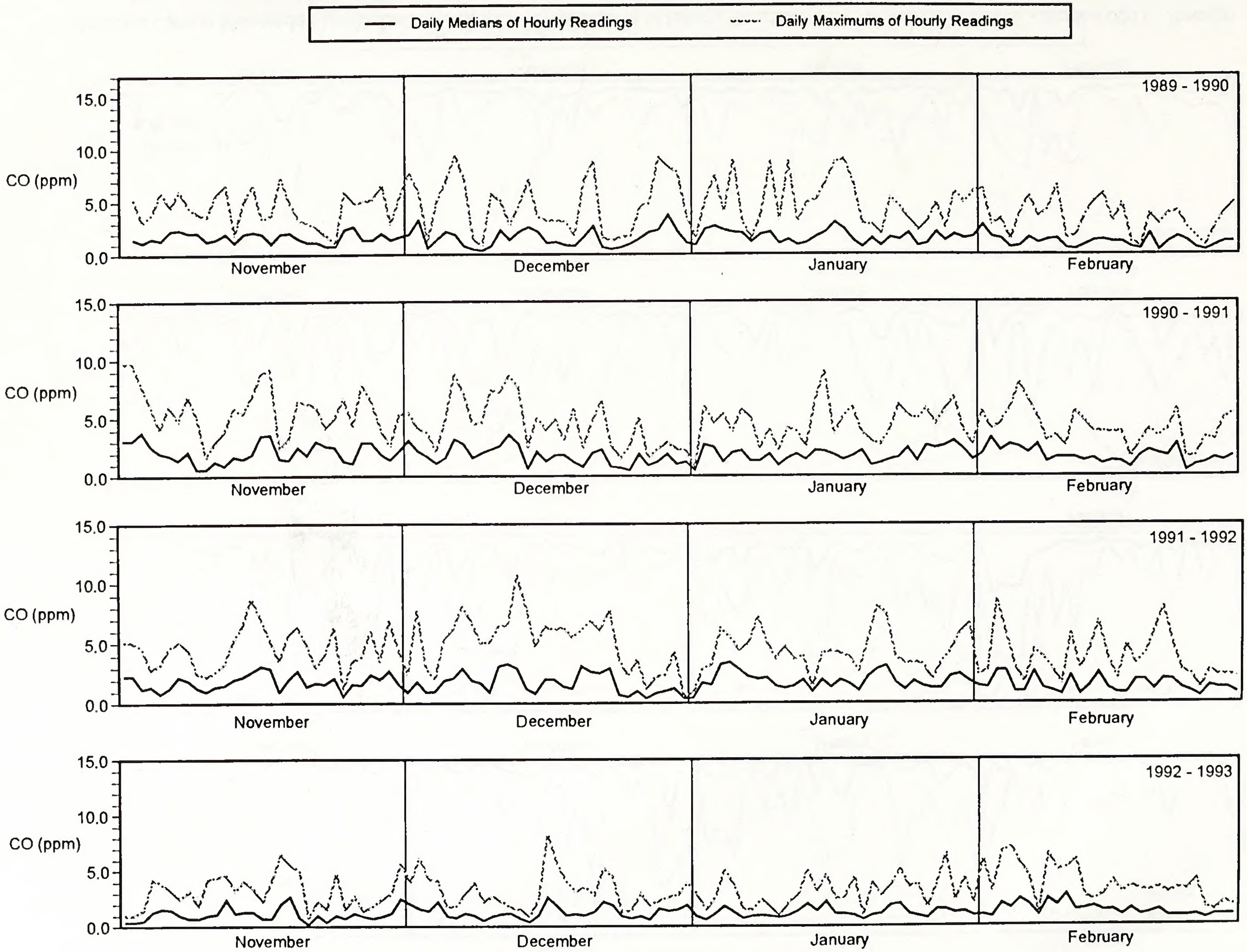
(Daily Medians of Hourly Readings - By Day of the Week for November 1992 through February 1993)

Appendix E

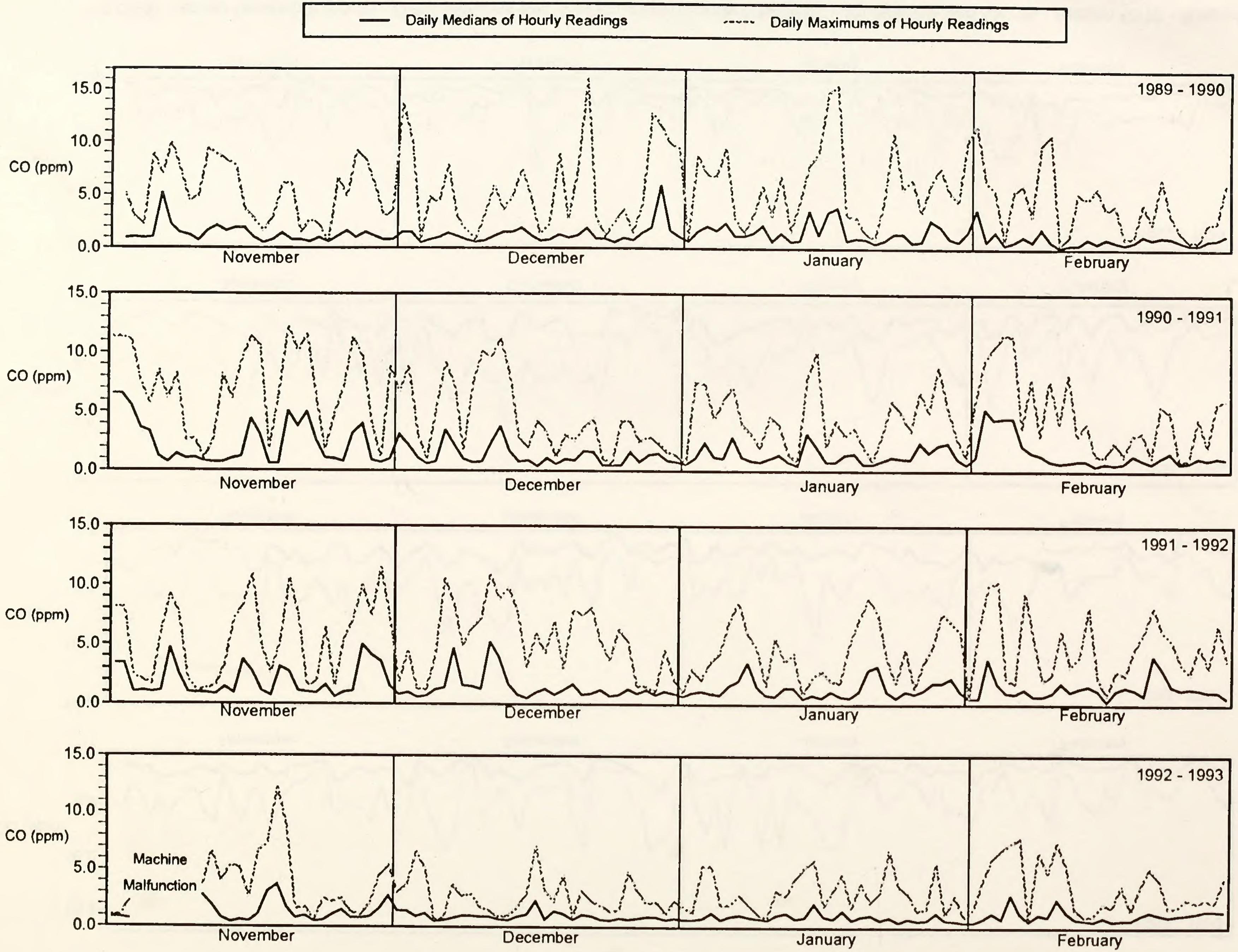


Ambient Carbon Monoxide - November 1992 - Station 0013 - Raleigh
Frequency Distributions of Hourly Readings (shown with estimated normal distributions)

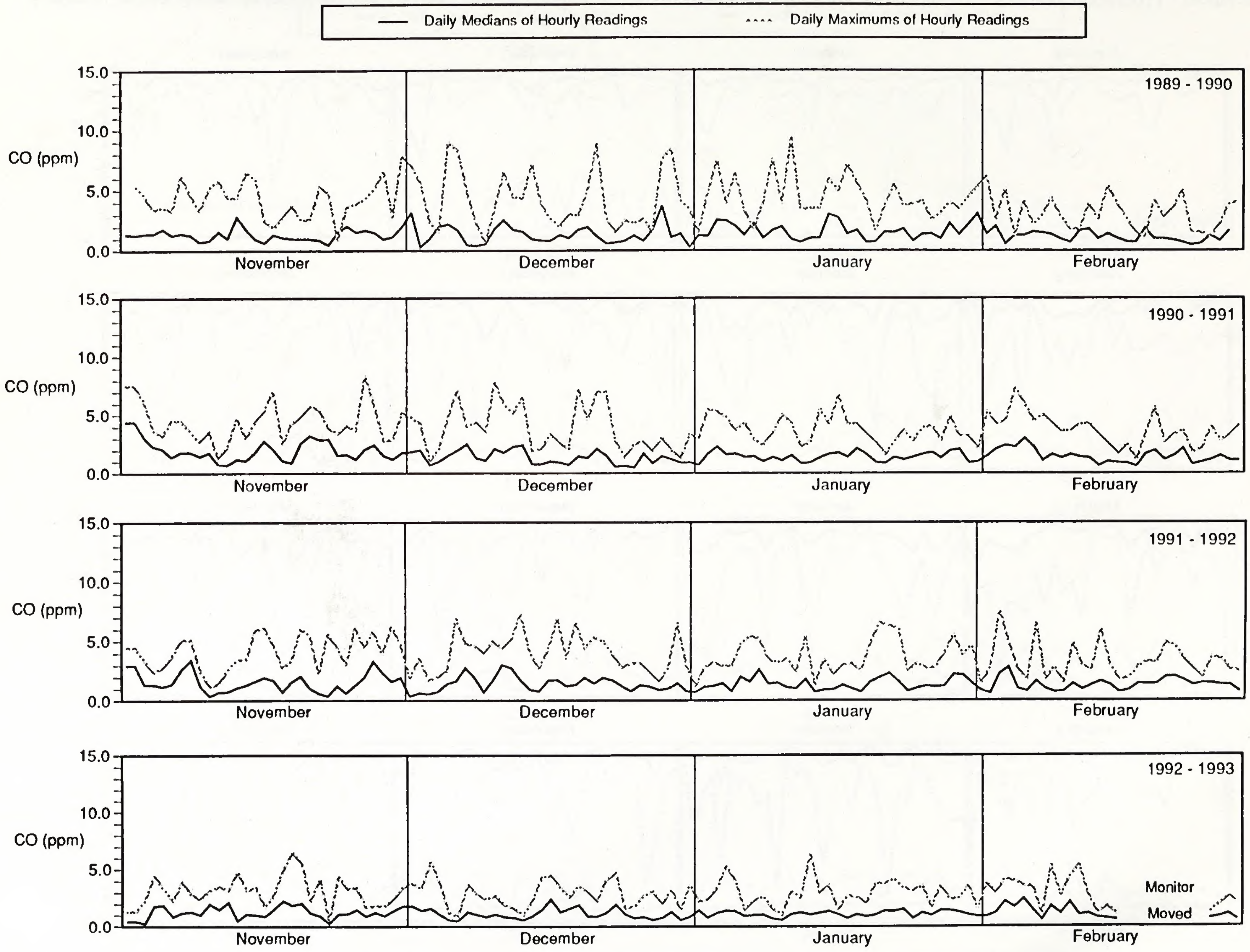
Appendix F.1



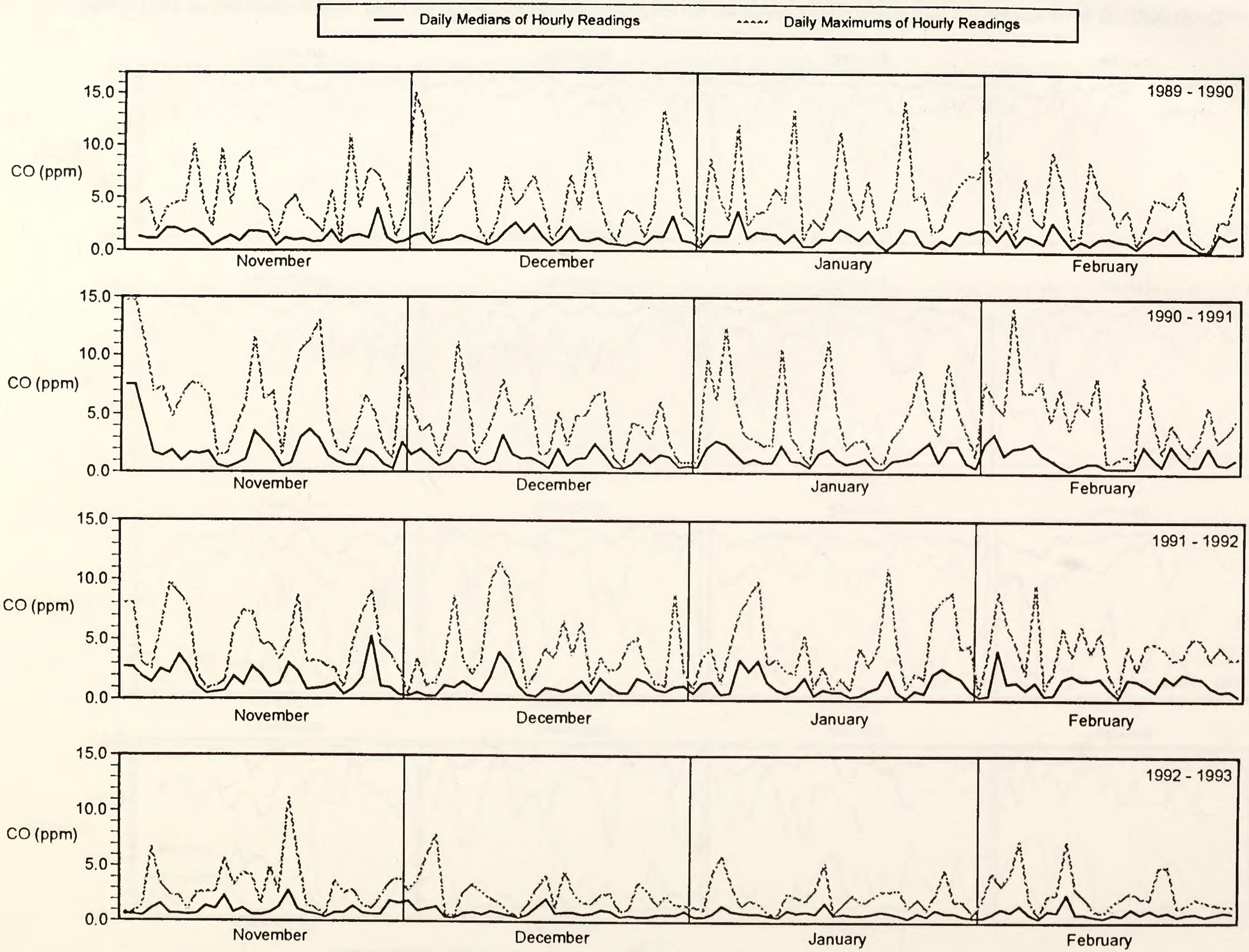
Ambient Carbon Monoxide (ppm) - Daily Medians and Maximums of Hourly Readings - By Season and Month - Station 0013 - Raleigh



Ambient Carbon Monoxide (ppm) - Daily Medians and Maximums of Hourly Readings - By Season and Month - Station 0011 - Raleigh

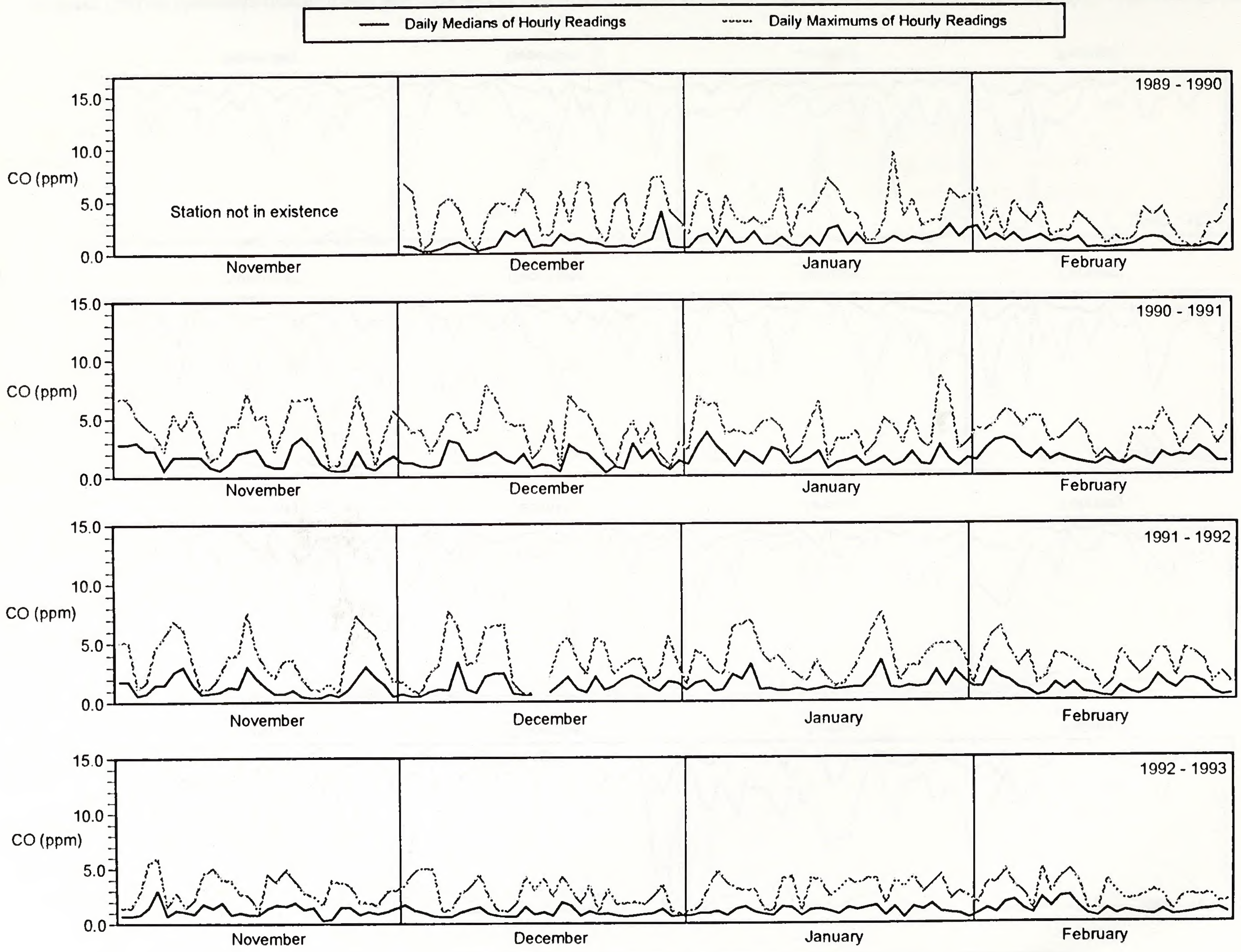


Ambient Carbon Monoxide (ppm)- Daily Medians and Maximums of Hourly Readings - By Season and Month - Stations 0010/0012 - Durham

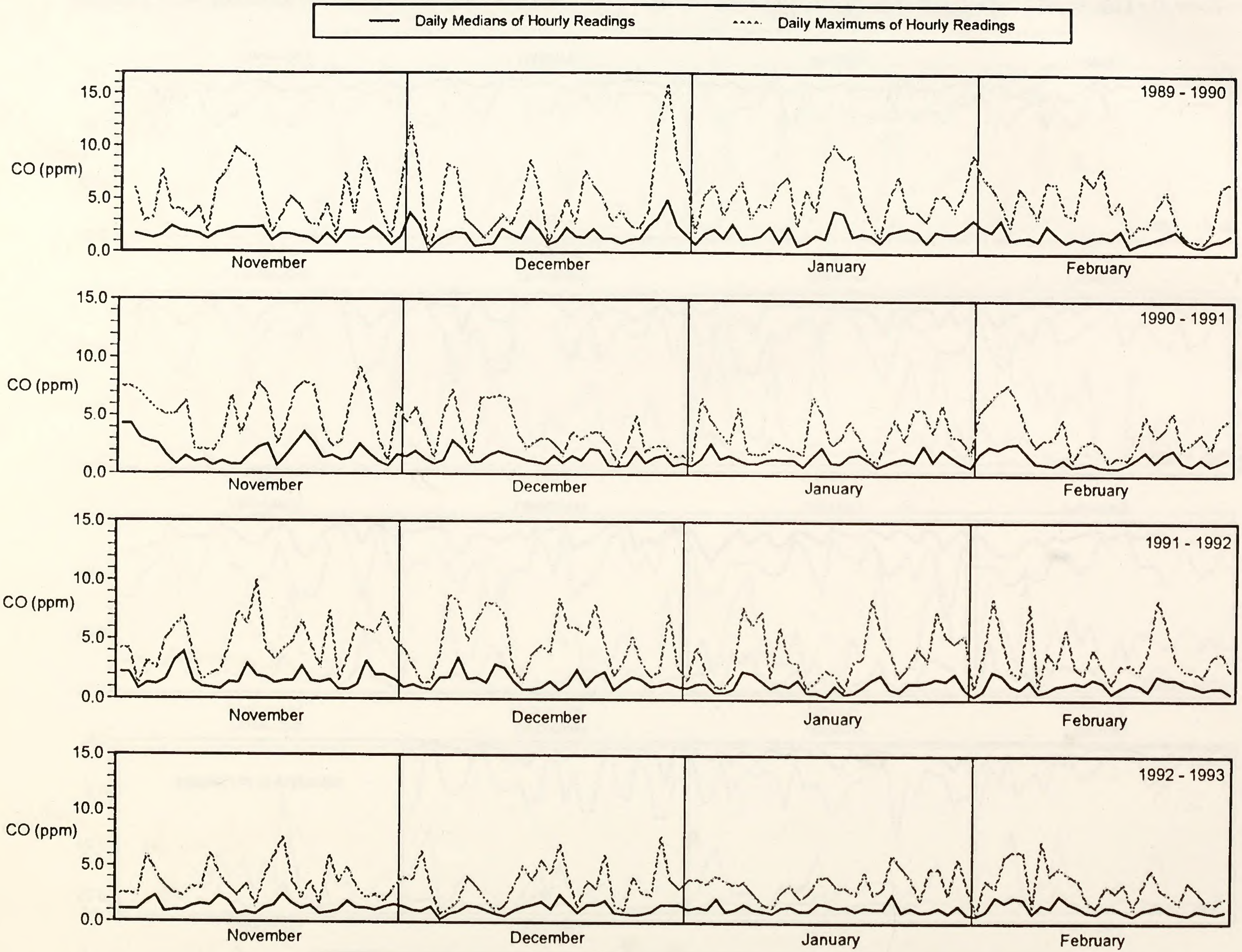


Ambient Carbon Monoxide (ppm) - Daily Medians and Maximums of Hourly Readings - By Season and Month - Stations 0008/0011 - Durham

Appendix F.5

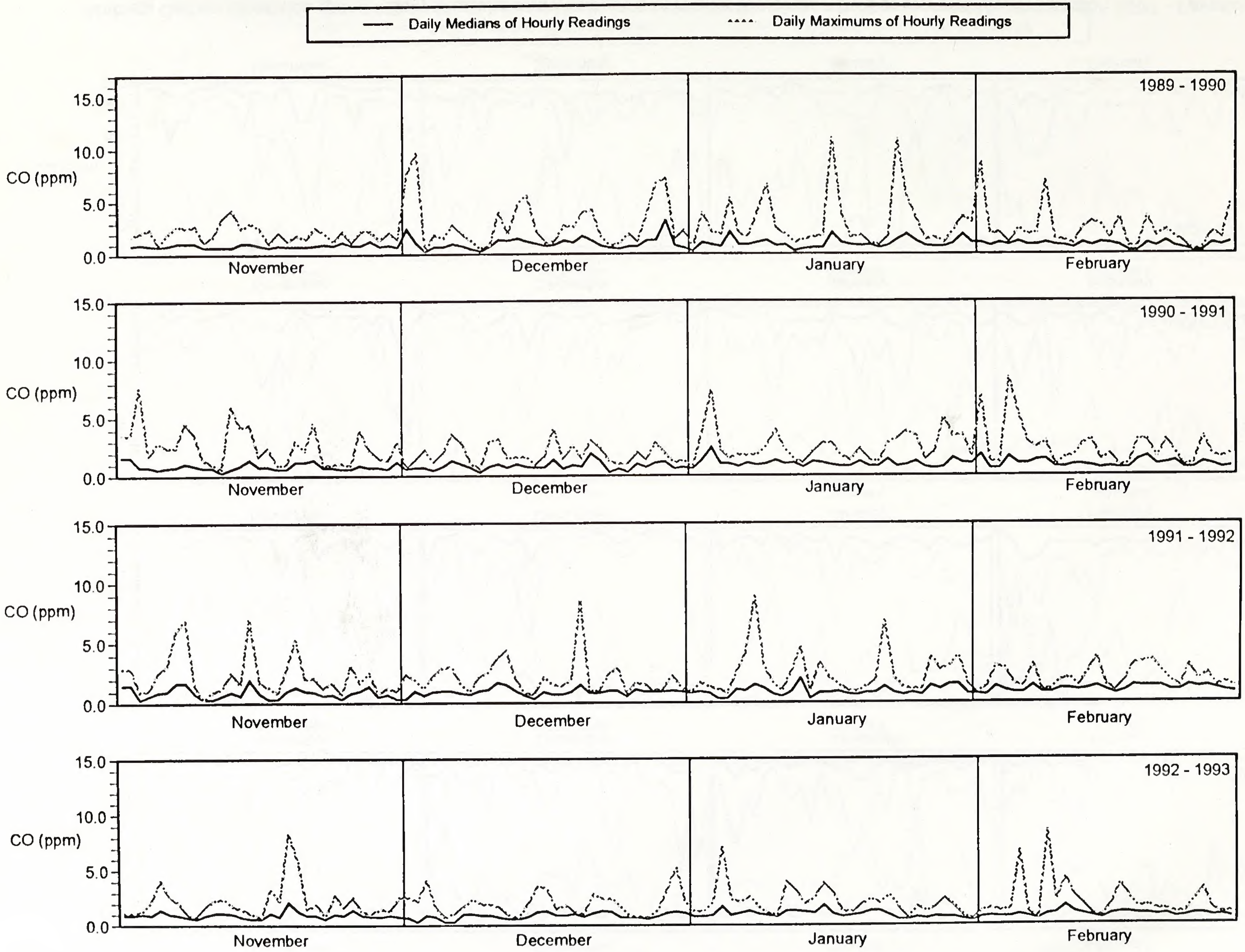


Ambient Carbon Monoxide (ppm) - Daily Medians and Maximums of Hourly Readings - By Season and Month - Station 1011 - Greensboro



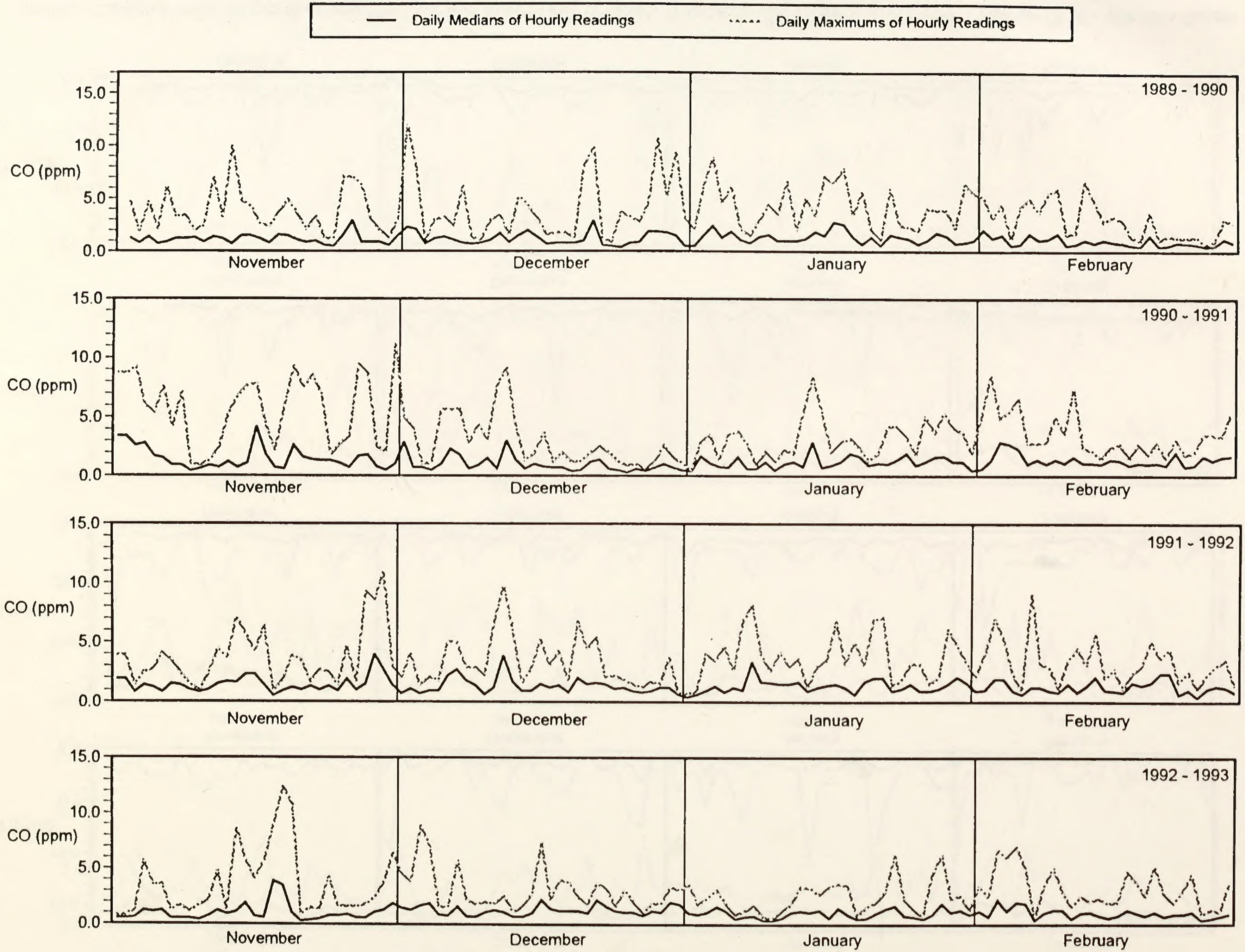
Ambient Carbon Monoxide (ppm) - Daily Medians and Maximums of Hourly Readings - By Season and Month - Station 0023 - Winston-Salem

Appendix F.7

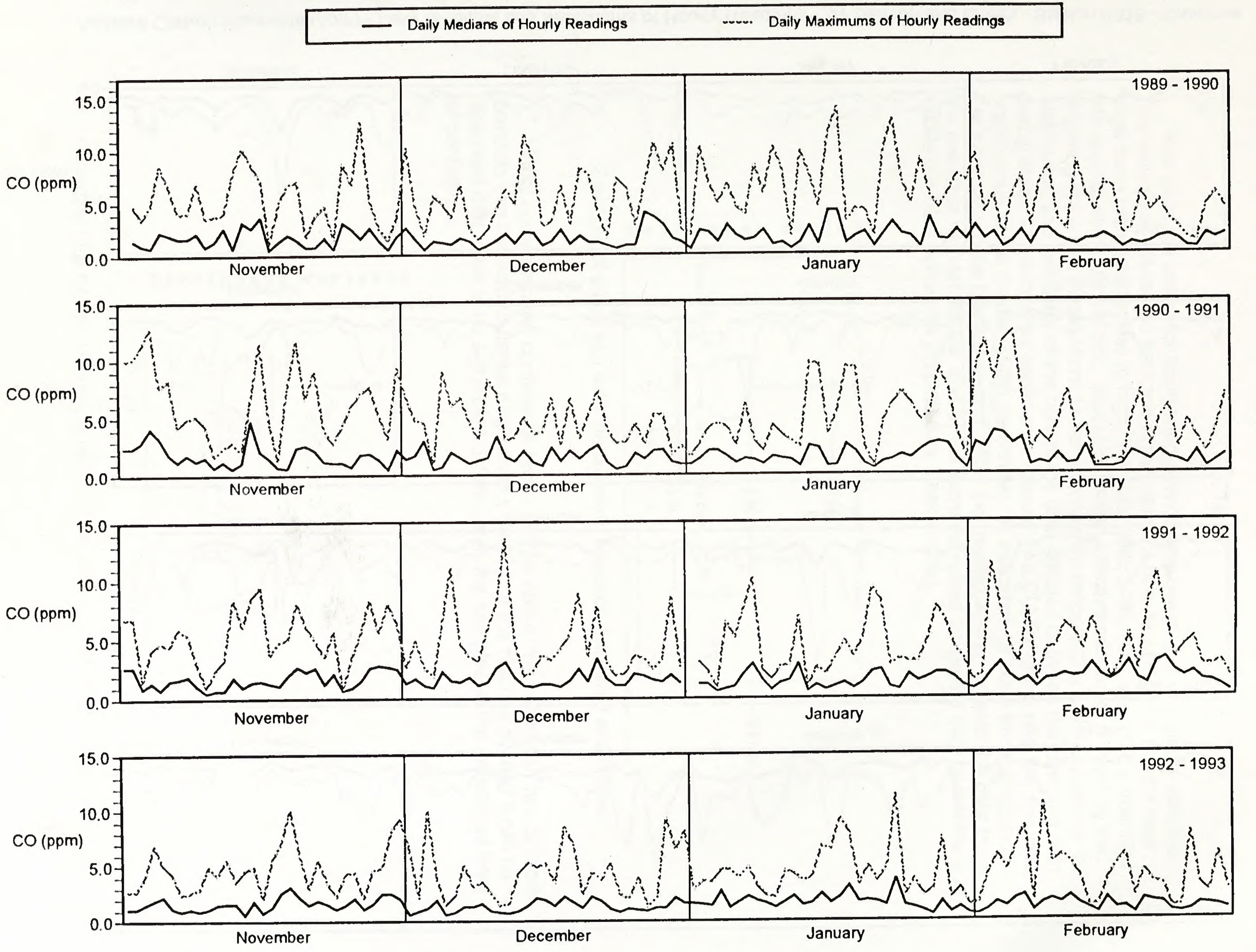


Ambient Carbon Monoxide (ppm) - Daily Medians and Maximums of Hourly Readings - By Season and Month - Station 0018 - Winston-Salem

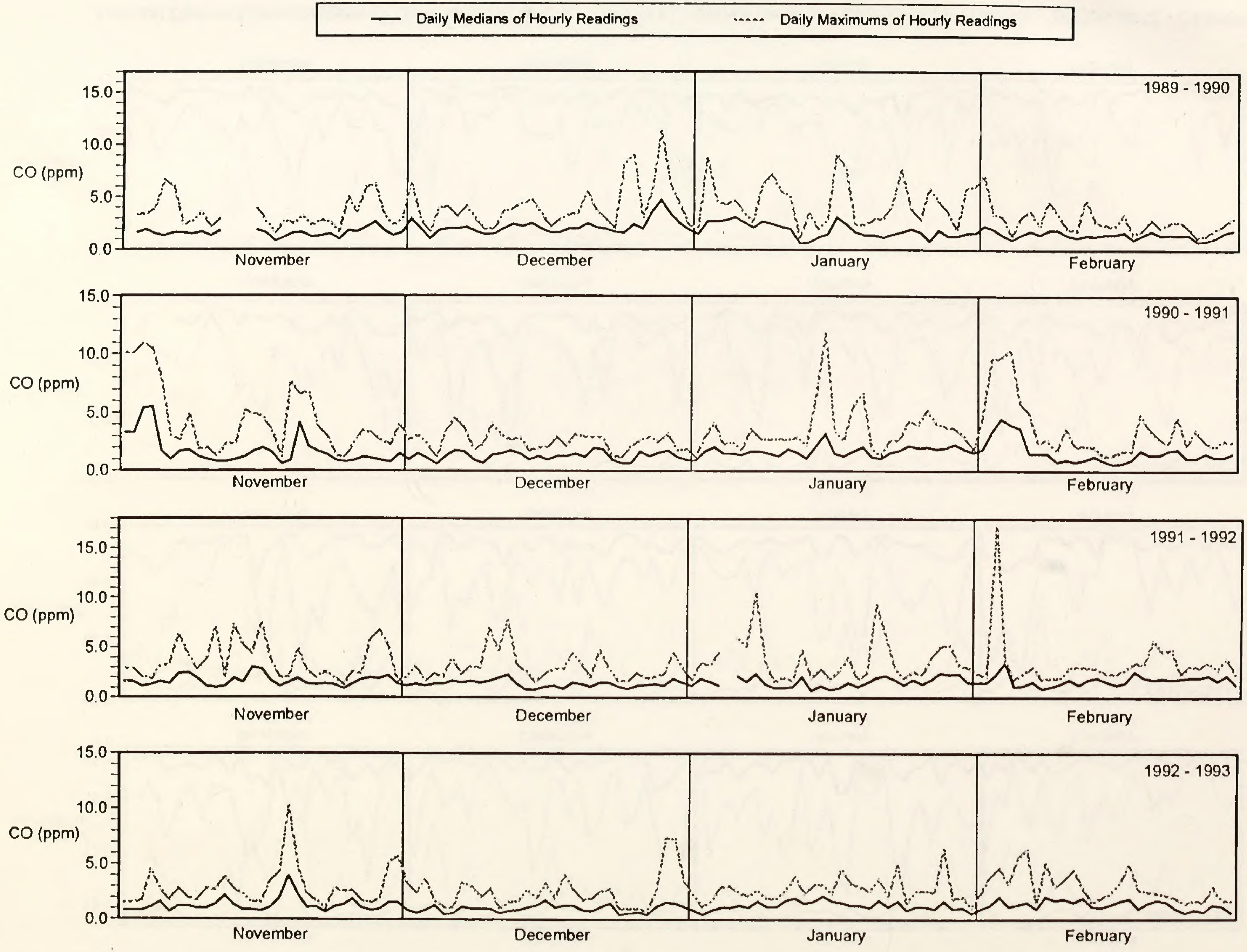
Appendix F.8



Ambient Carbon Monoxide (ppm) - Daily Medians and Maximums of Hourly Readings - By Season and Month - Station 0007 - Fayetteville



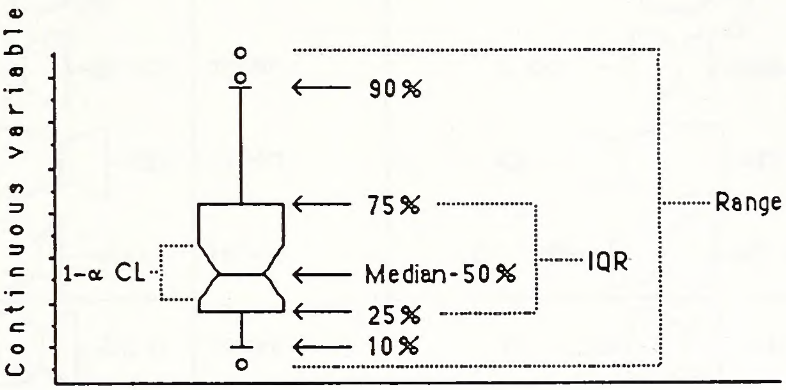
Ambient Carbon Monoxide (ppm) - Daily Medians and Maximums of Hourly Readings - By Season and Month - Station 0032 - Charlotte



Ambient Carbon Monoxide (ppm) - Daily Medians and Maximums of Hourly Readings - By Season and Month - Station 0038 - Charlotte

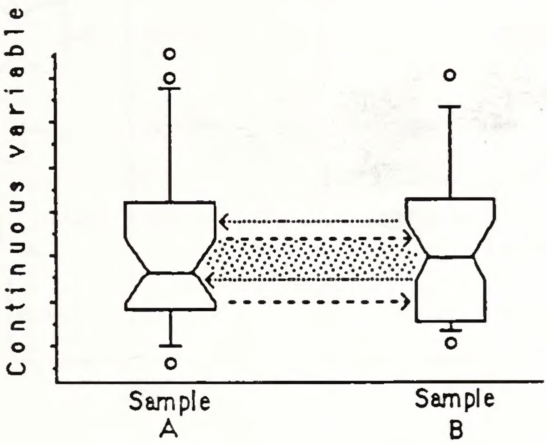
BOX PLOTS

Box plots are useful for comparing sets of data comprised of a single variable. This technique visualizes selected order statistics of a dataset After the the data have been ordered from low to high, the 10th, 25th, 50th, 75th, and 90th percentiles are used to construct the plot. Box plots are an effective method of presenting the following important information: 1) the interquartile range (IQR) which measures the distribution and variability of the bulk of the data (located between the 25th and 75th percentiles), 2) the desired confidence interval (1-a CL) for measuring the statistical significance of the median (50th percentile), 3) indication of skew from comparing the symmetry of the box above and below the median, 4) the range of the data from the lowest to highest values, and 5) the extreme values below the 10th percentile and above the 90th percentile (depicted as small circles).

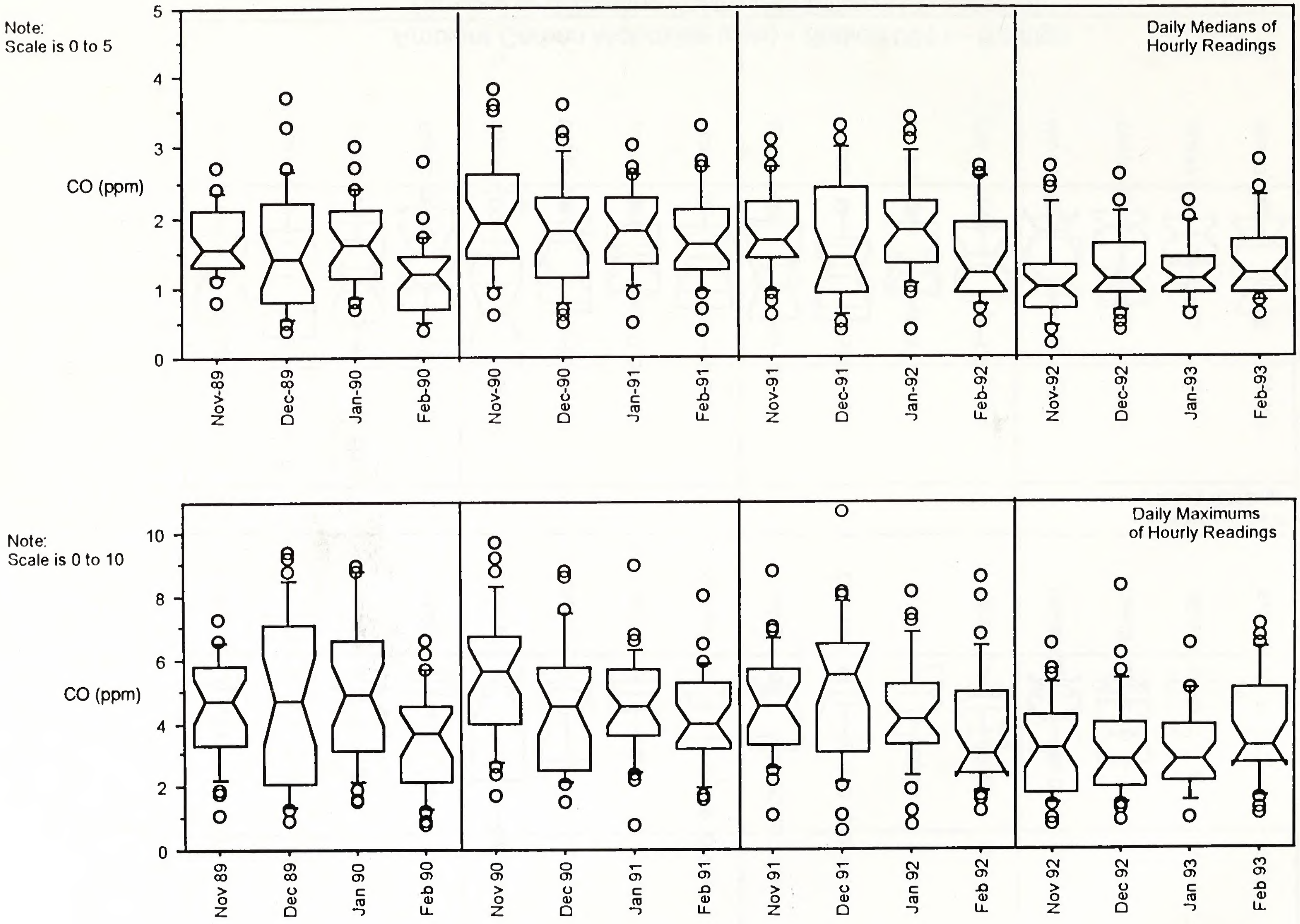


Example of a box plot with the different statistics illustrated and labeled.

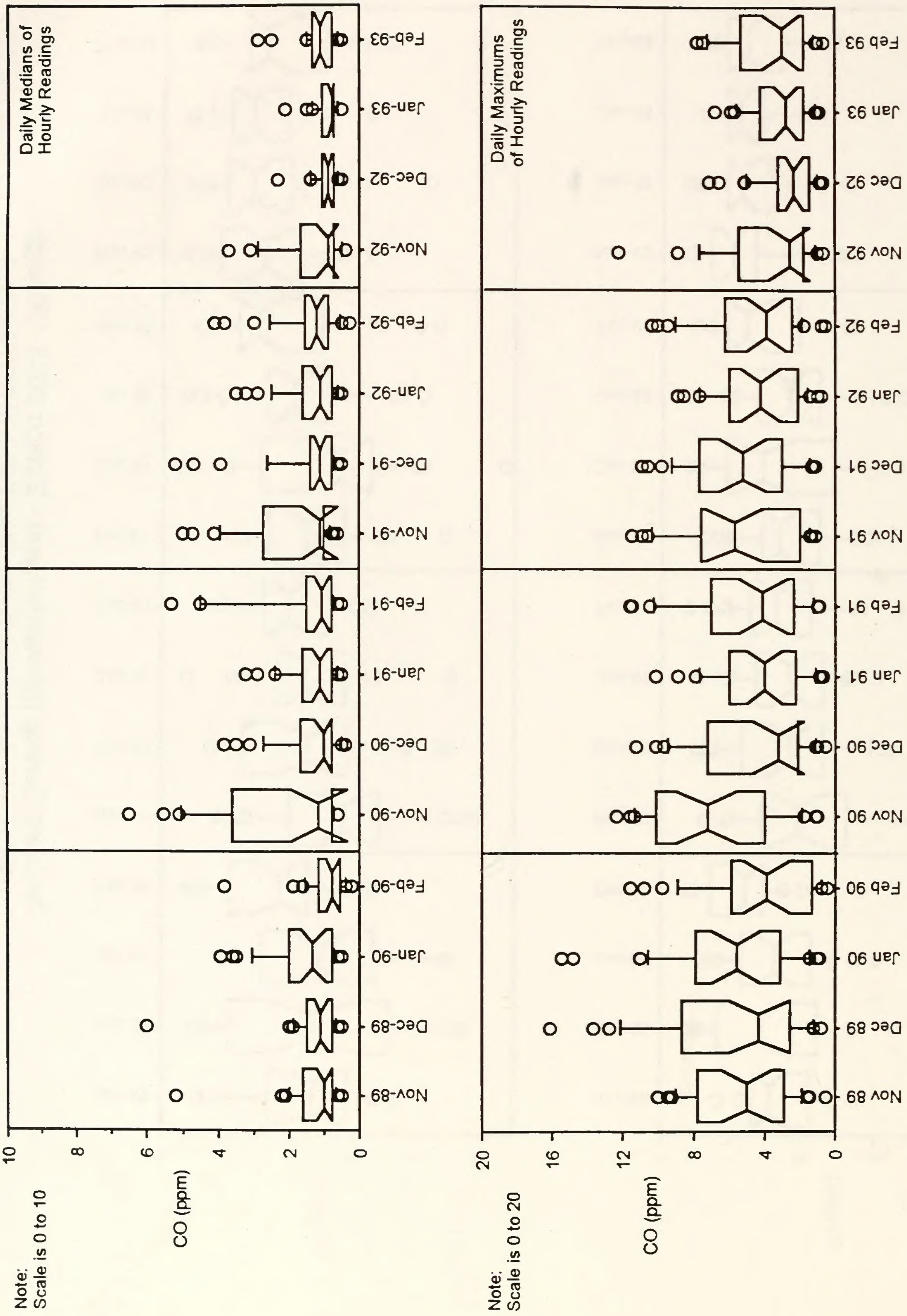
Visual comparison of confidence level notches about the medians of two or more boxplots can be used to perform hypothesis testing. If the notches overlap it can be assumed that there is no significant difference in the samples at the prescribed level of confidence.



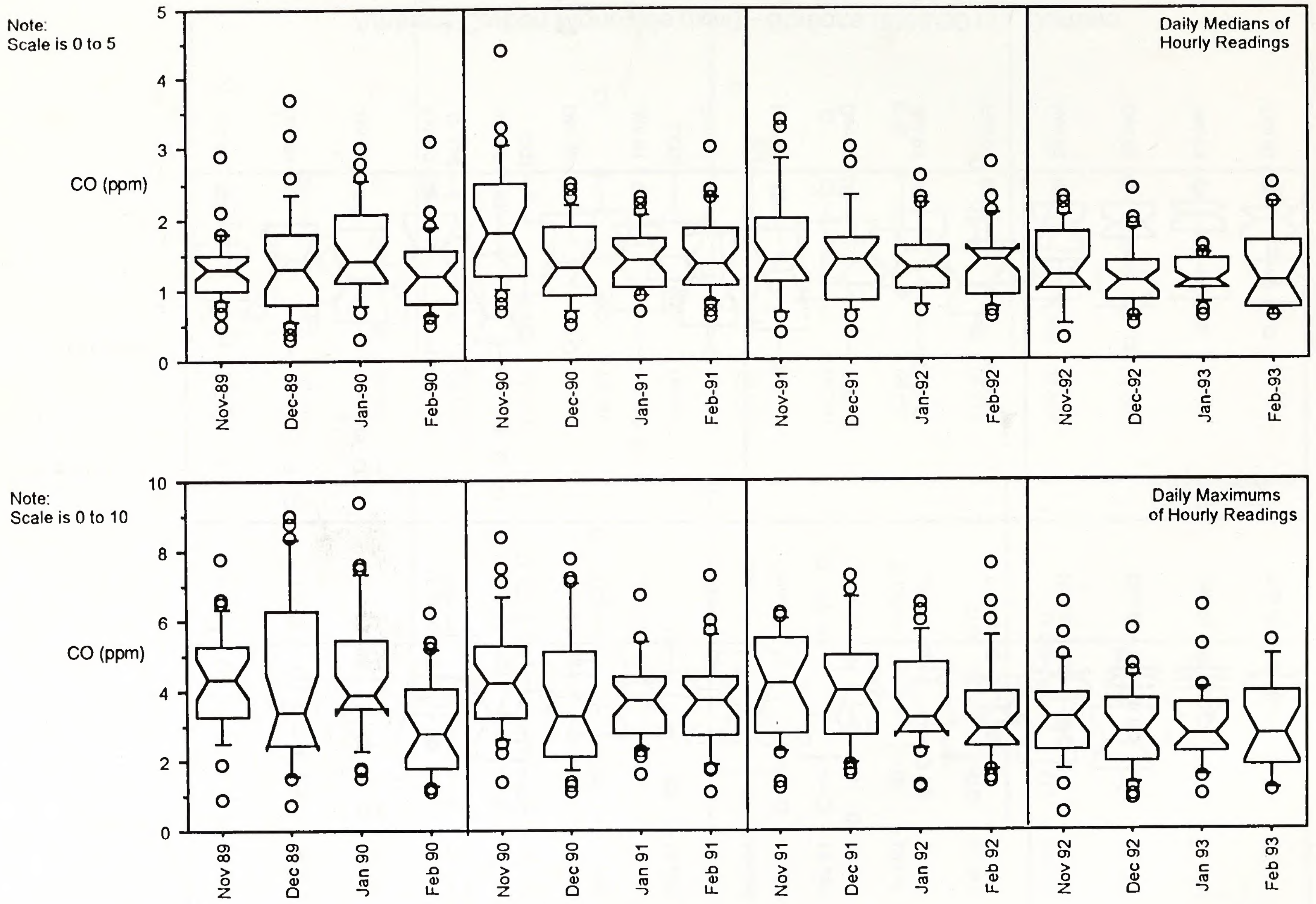
Example of a box plot showing two samples with no significant difference.



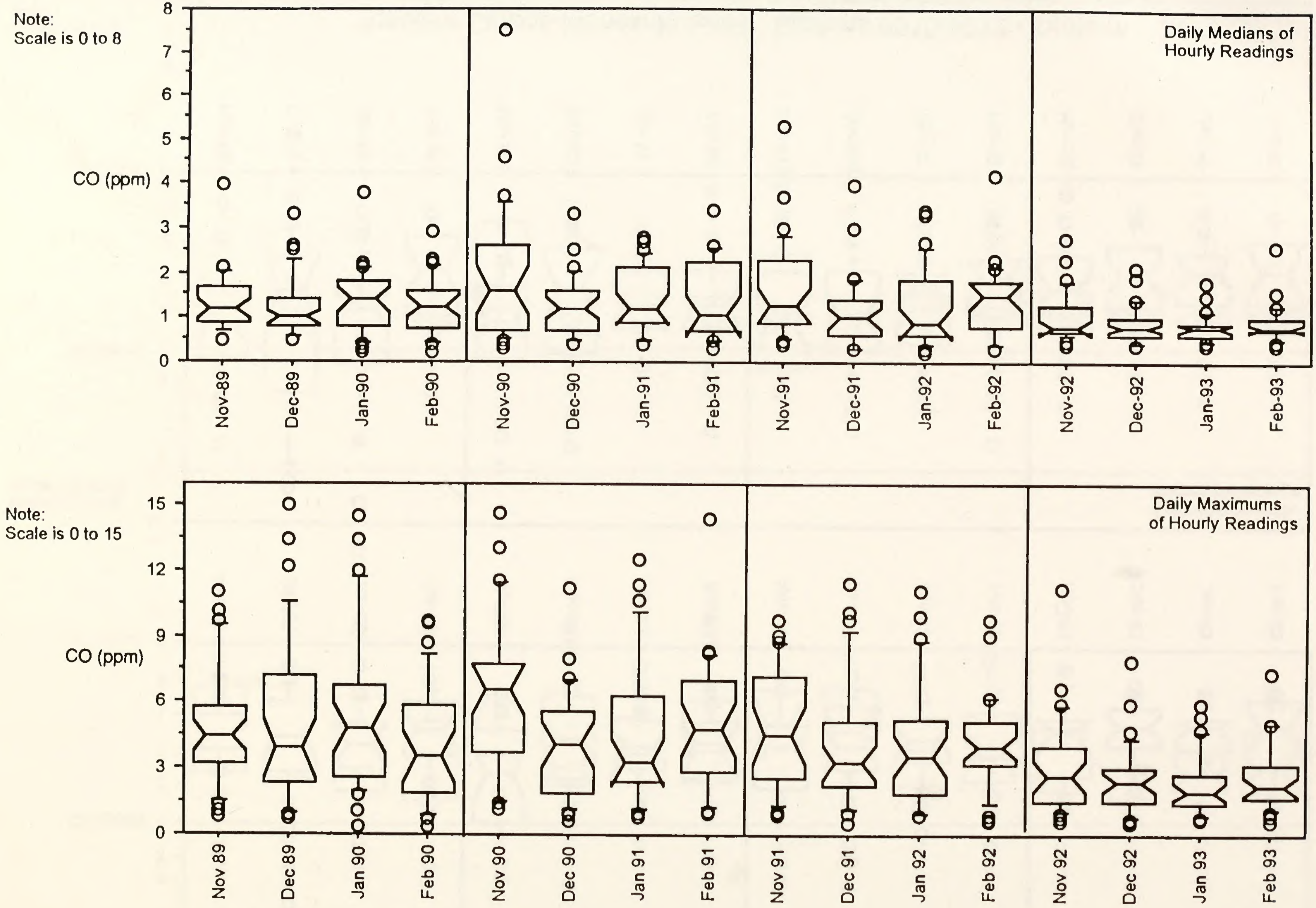
Ambient Carbon Monoxide (ppm) - Station 0013 - Raleigh
(Grouped by Successive Months Over Different CO Seasons)



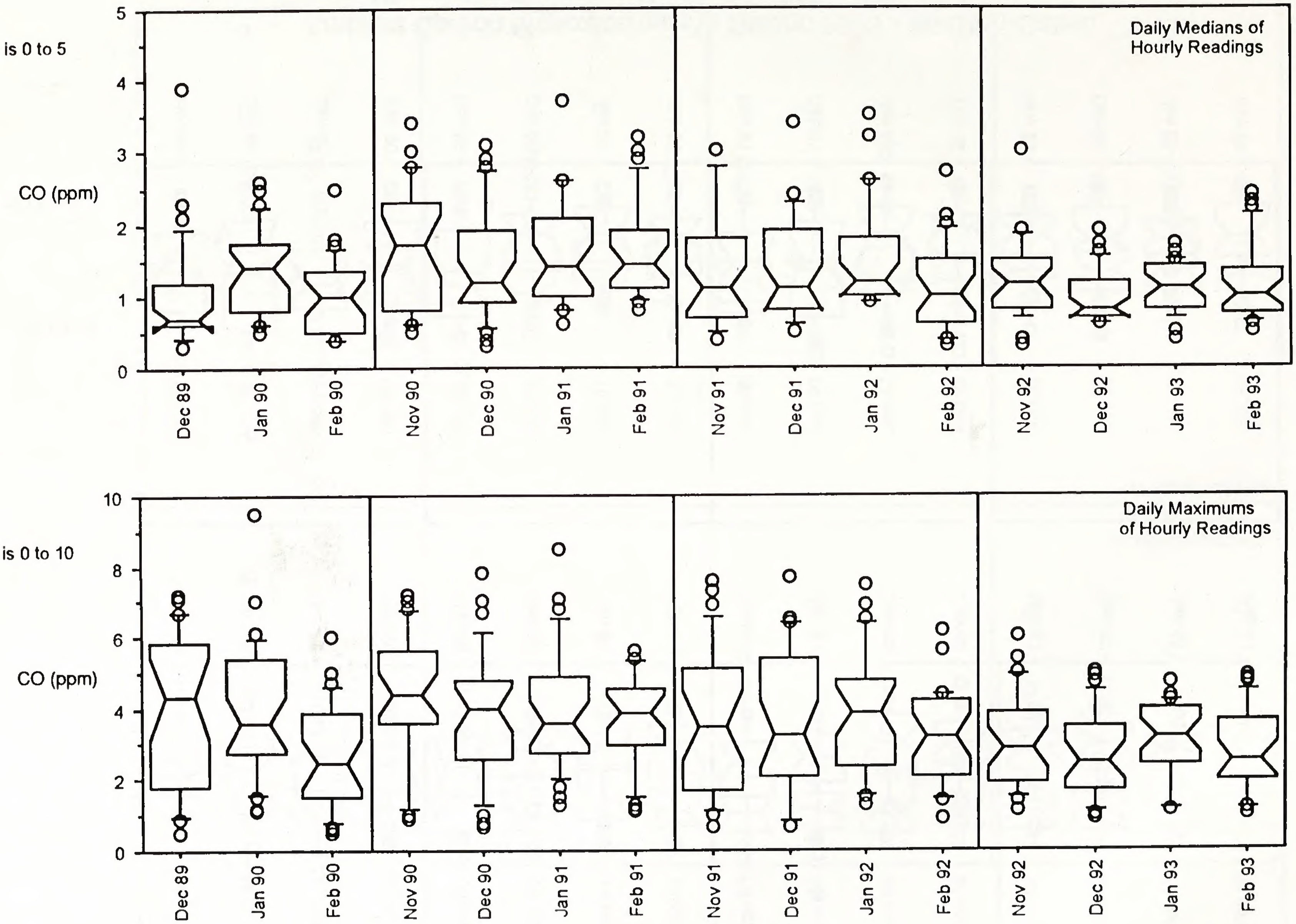
Ambient Carbon Monoxide (ppm) - Station 0011 - Raleigh
(Grouped by Successive Months Over Different CO Seasons)



Ambient Carbon Monoxide (ppm) - Stations 0010/0012 - Durham
(Grouped by Successive Months Over Different CO Seasons)



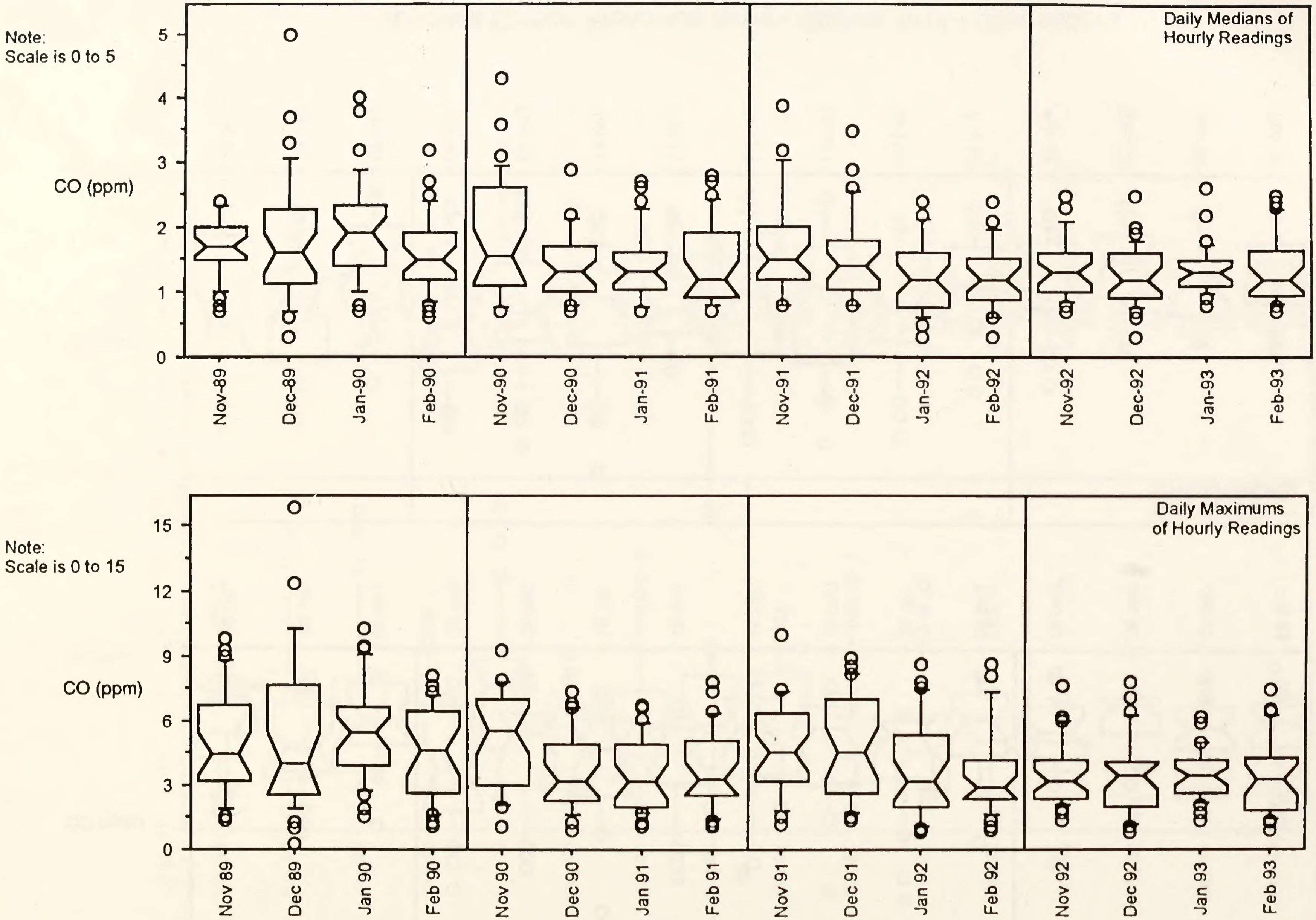
Ambient Carbon Monoxide (ppm) - Stations 0008/0011 - Durham
(Grouped by Successive Months Over Different CO Seasons)



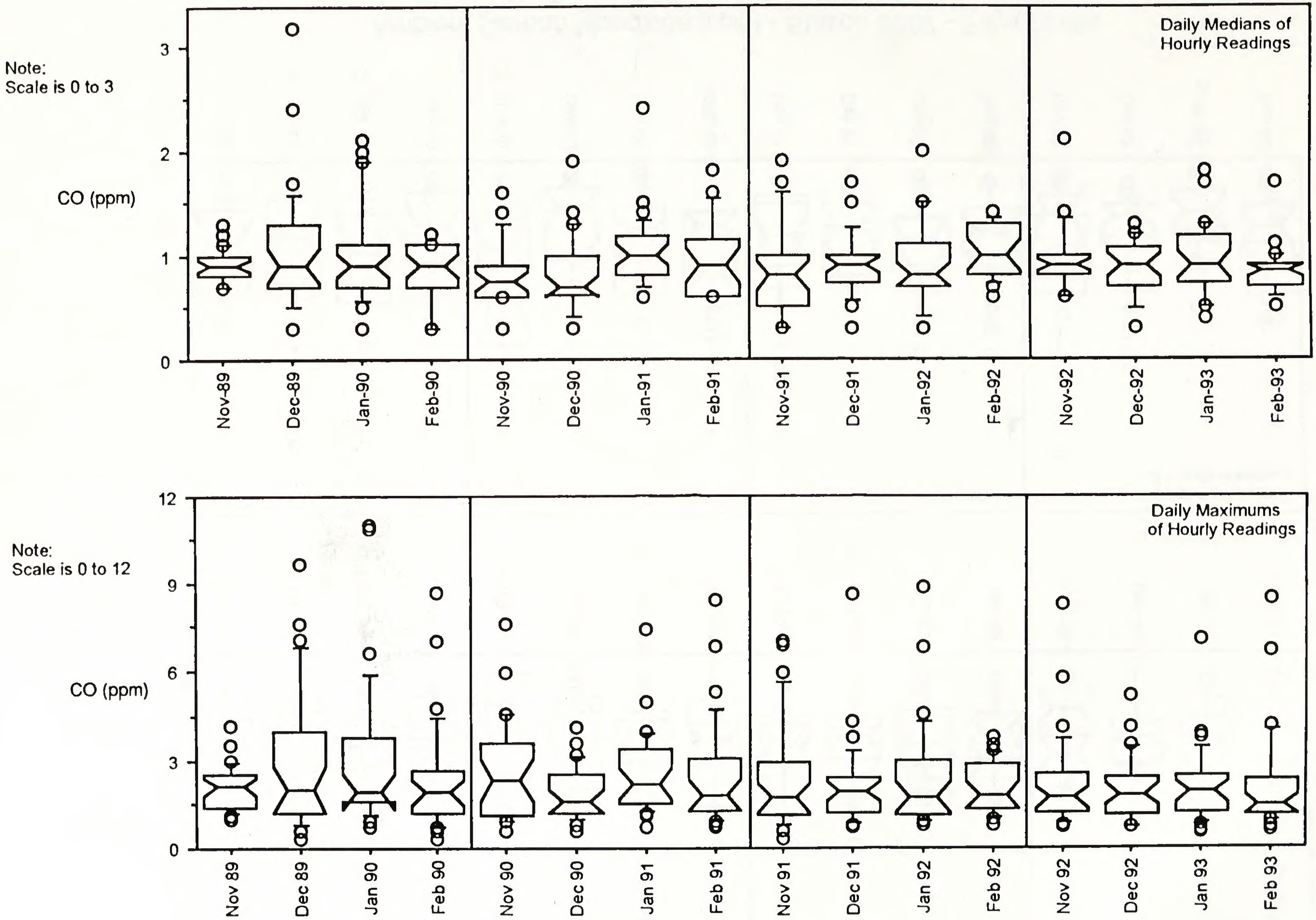
Note:
Scale is 0 to 5

Note:
Scale is 0 to 10

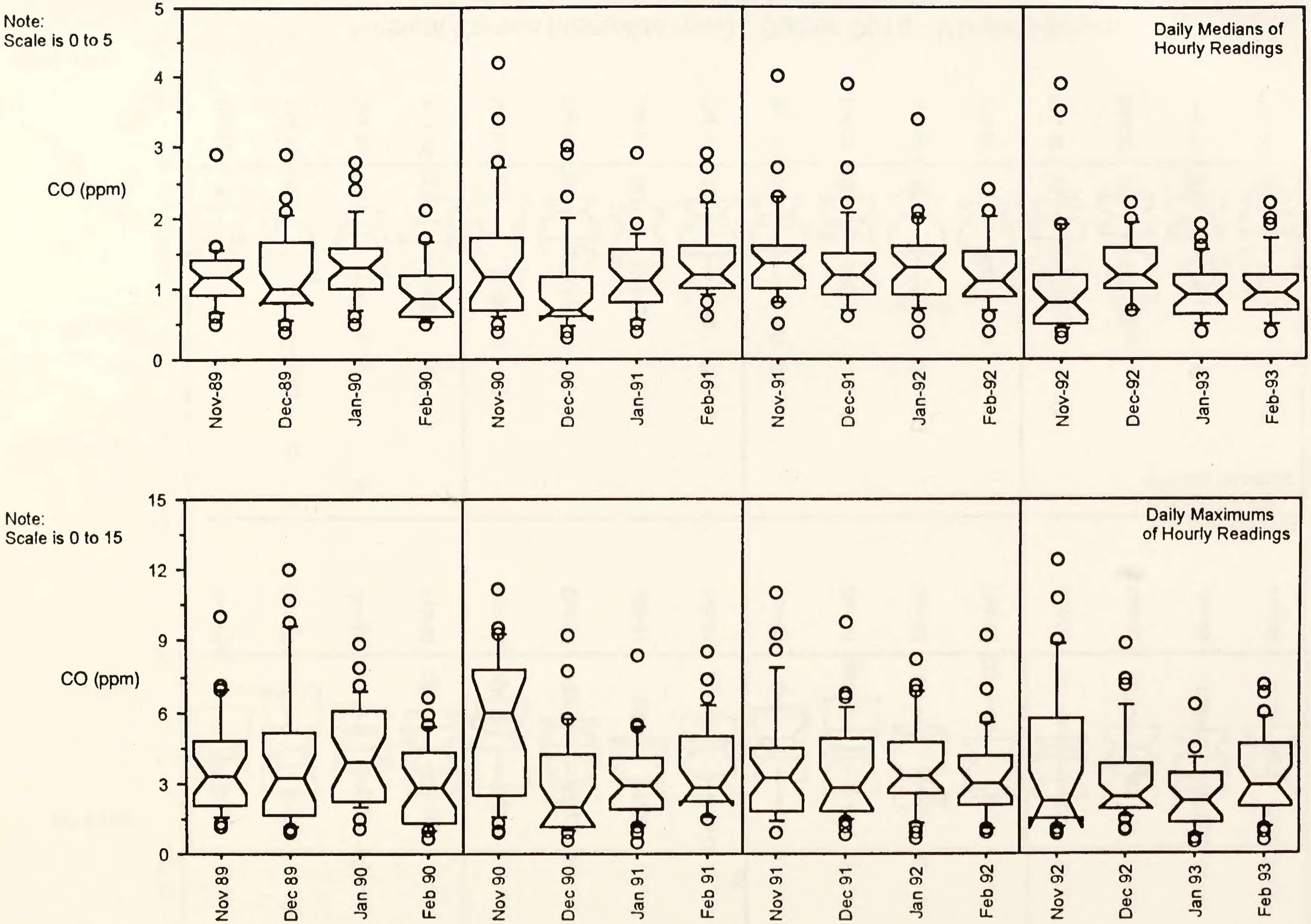
Ambient Carbon Monoxide (ppm) - Station 1011 - Greensboro
(Grouped by Successive Months Over Different CO Seasons)



Ambient Carbon Monoxide (ppm) - Station 0023 - Winston-Salem
(Grouped by Successive Months Over Different CO Seasons)

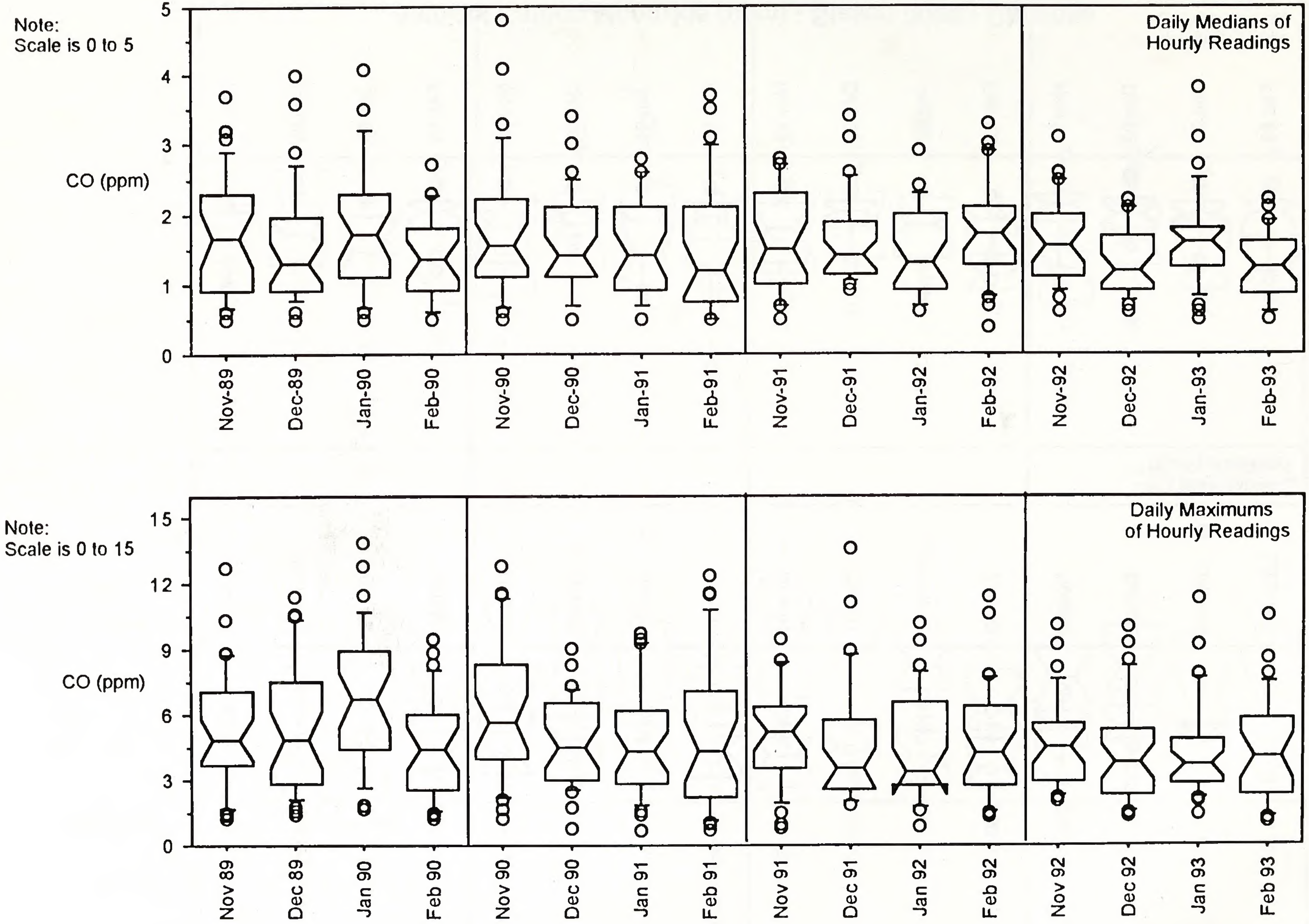


Ambient Carbon Monoxide (ppm) - Station 0018 - Winston-Salem
(Grouped by Successive Months Over Different CO Seasons)



Ambient Carbon Monoxide (ppm) - Station 0007 - Fayetteville

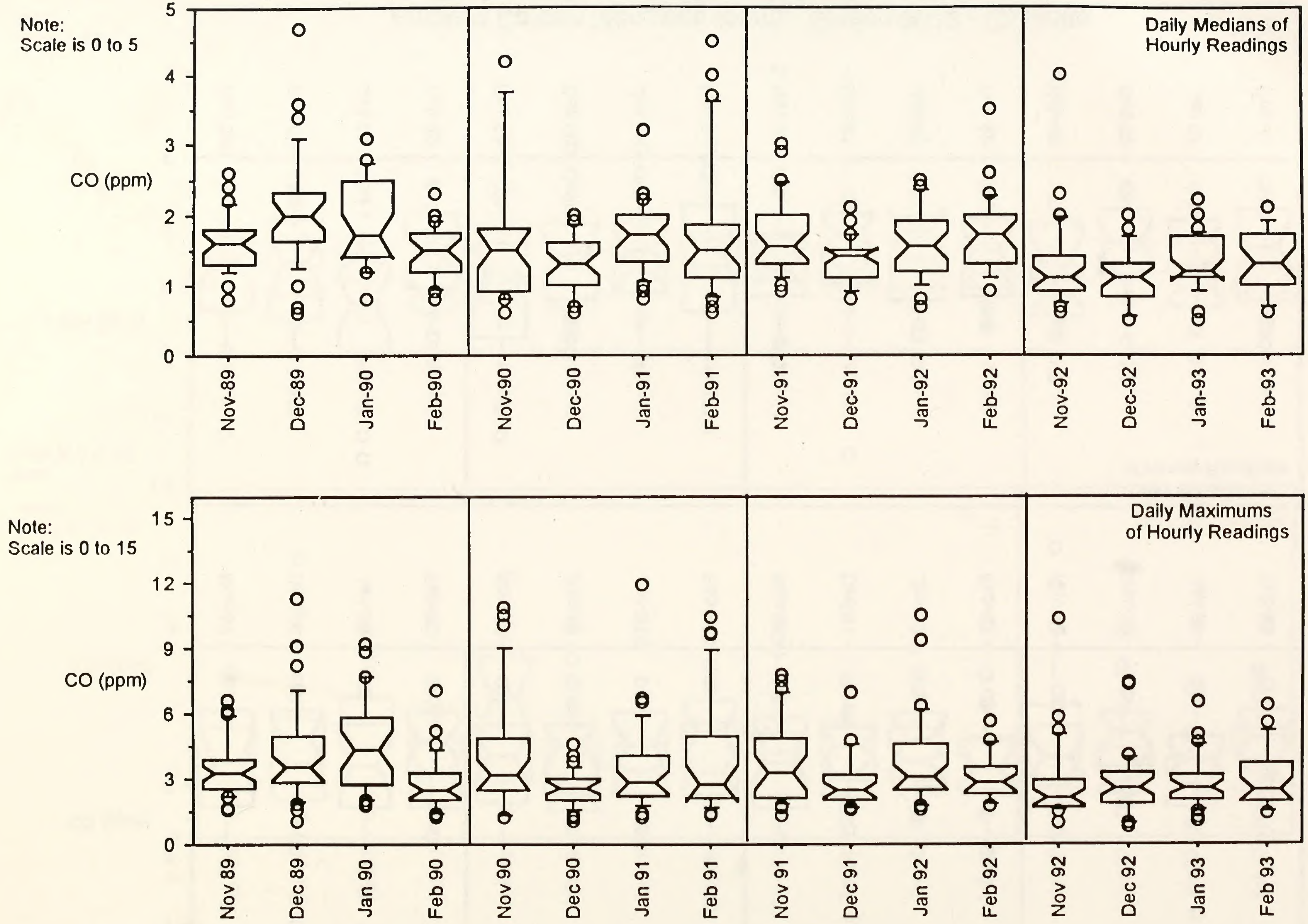
(Grouped by Successive Months Over Different CO Seasons)



Note:
Scale is 0 to 5

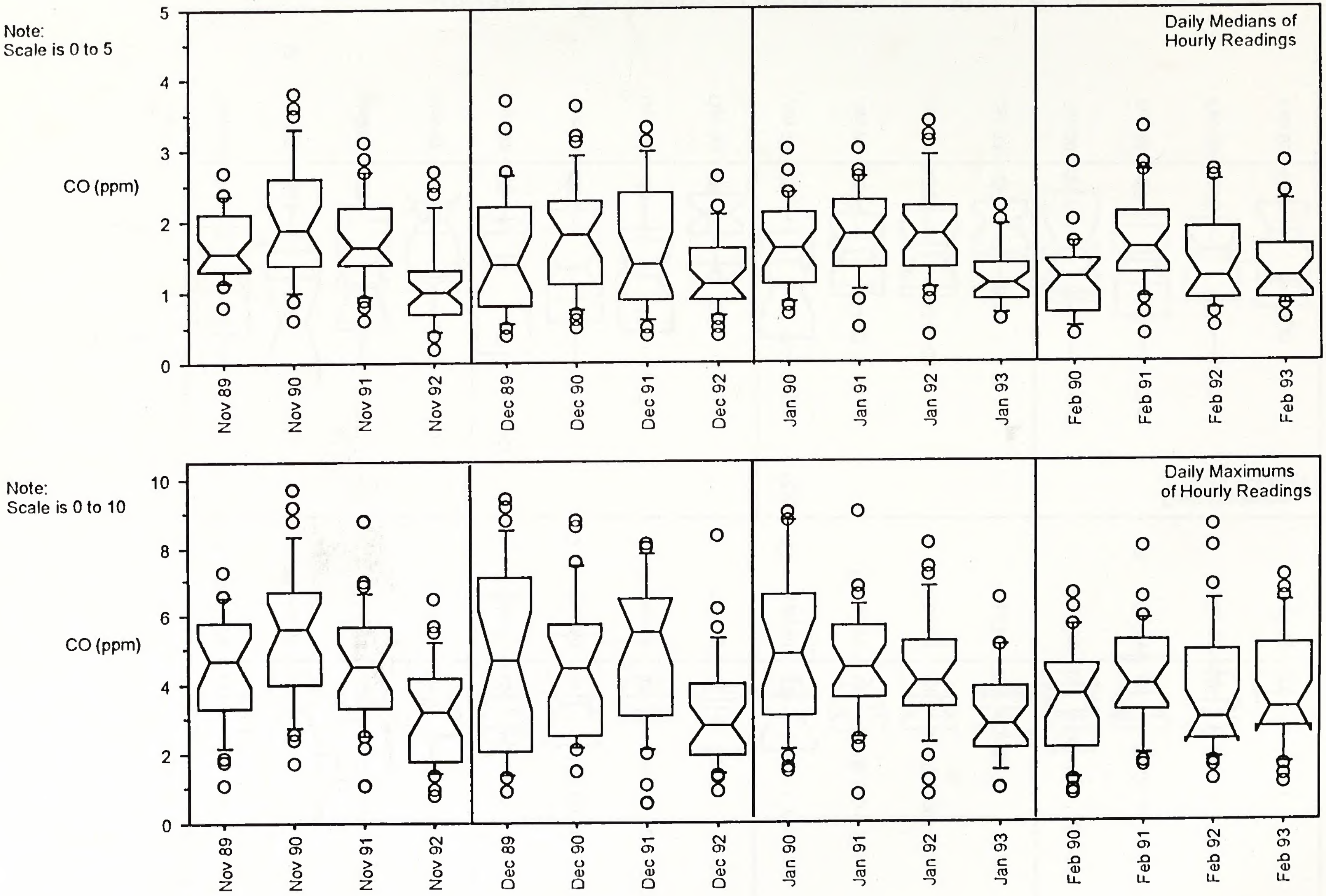
Note:
Scale is 0 to 15

Ambient Carbon Monoxide (ppm) - Station 0032 - Charlotte
(Grouped by Successive Months Over Different CO Seasons)

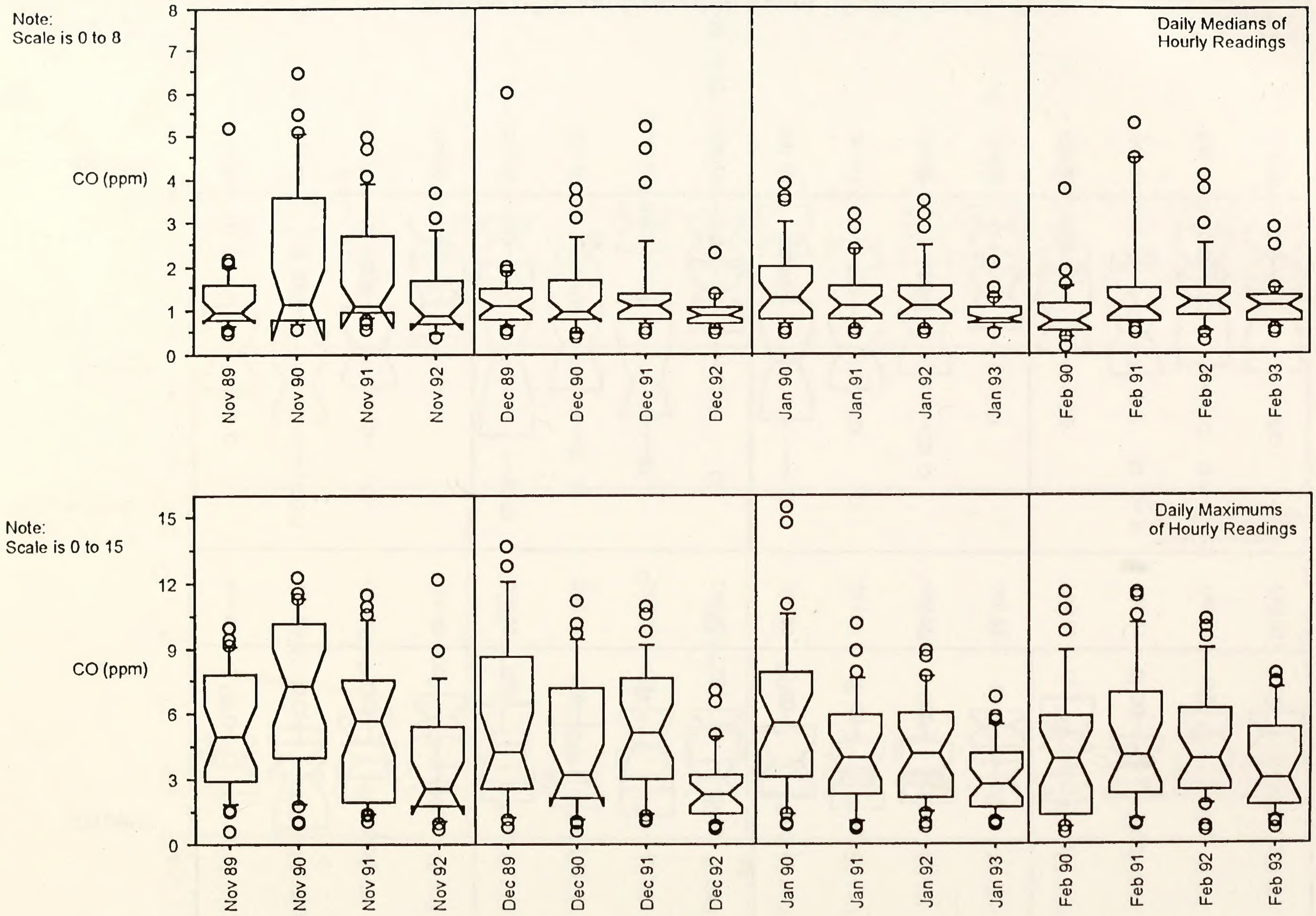

Note:
Scale is 0 to 5

Note:
Scale is 0 to 15

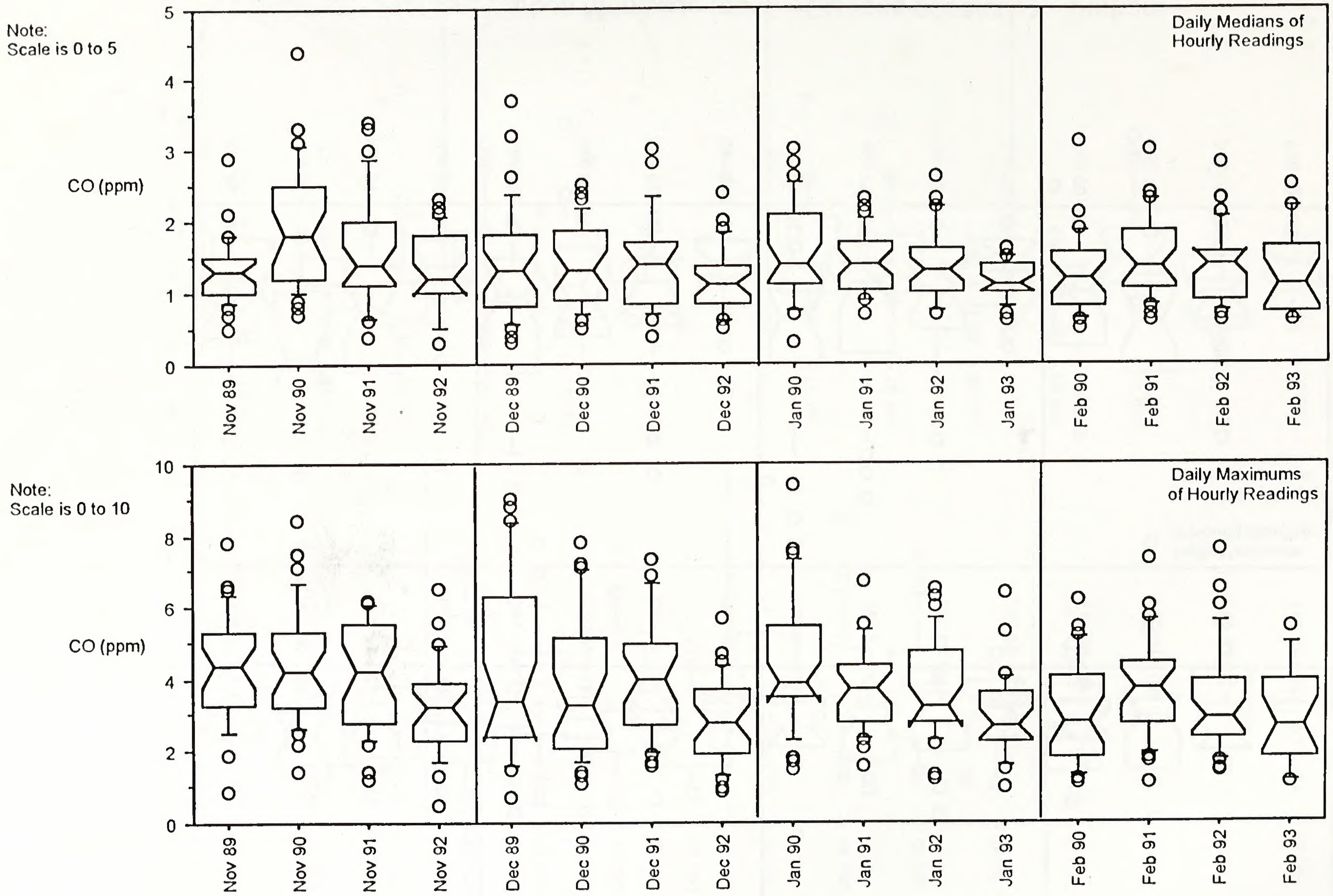
Ambient Carbon Monoxide (ppm) - Station 0038 - Charlotte
(Grouped by Successive Months Over Different CO Seasons)



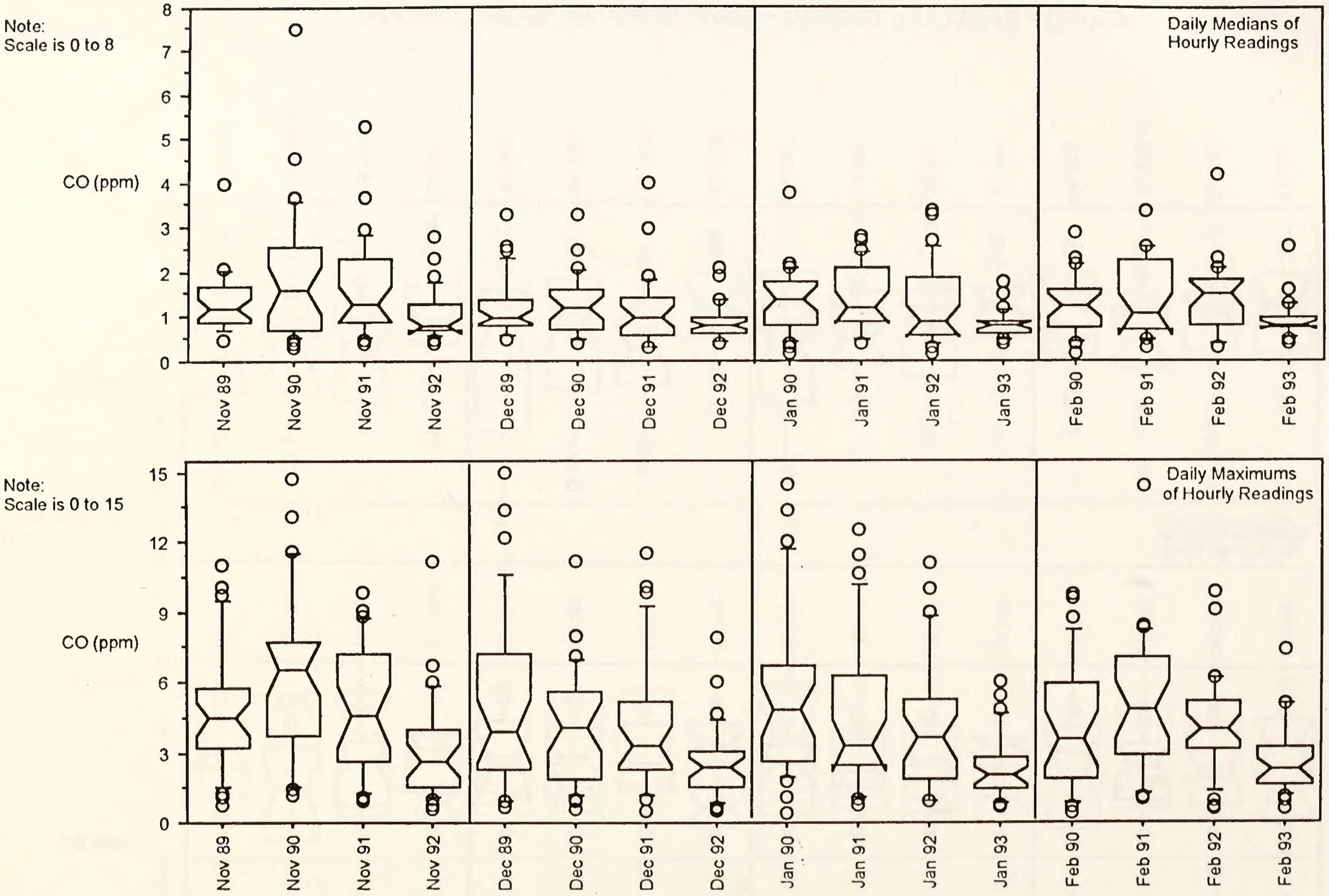
Ambient Carbon Monoxide (ppm) - Station 0013 - Raleigh
(Grouped by Similar Months Over Different Years)



Ambient Carbon Monoxide (ppm) - Station 0011 - Raleigh
(Grouped by Similar Months Over Different Years)

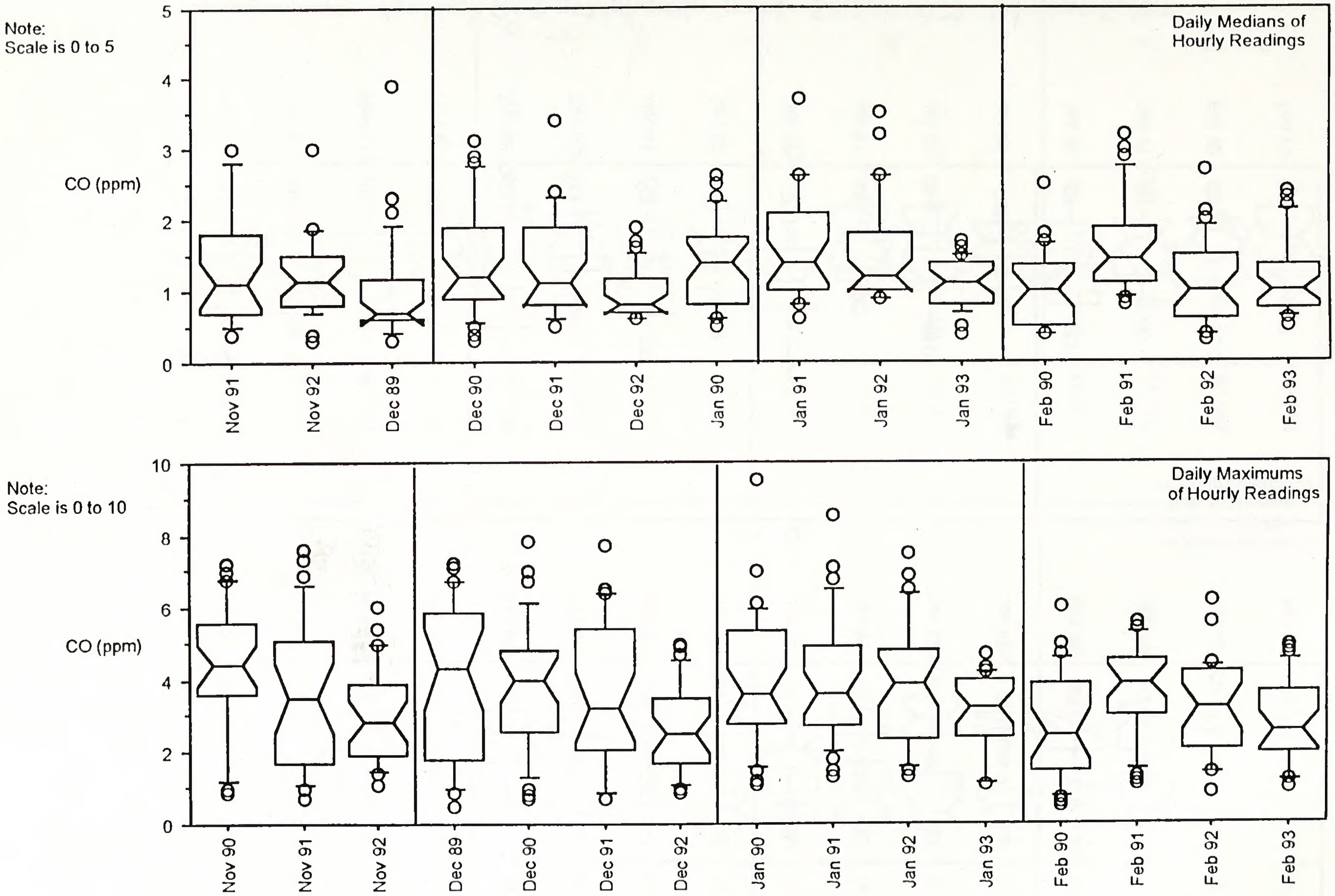


Ambient Carbon Monoxide (ppm) - Stations 0010/0012 - Durham
(Grouped by Similar Months Over Different Years)



Ambient Carbon Monoxide (ppm) - Stations 0008/0011 - Durham
(Grouped by Similar Months Over Different Years)

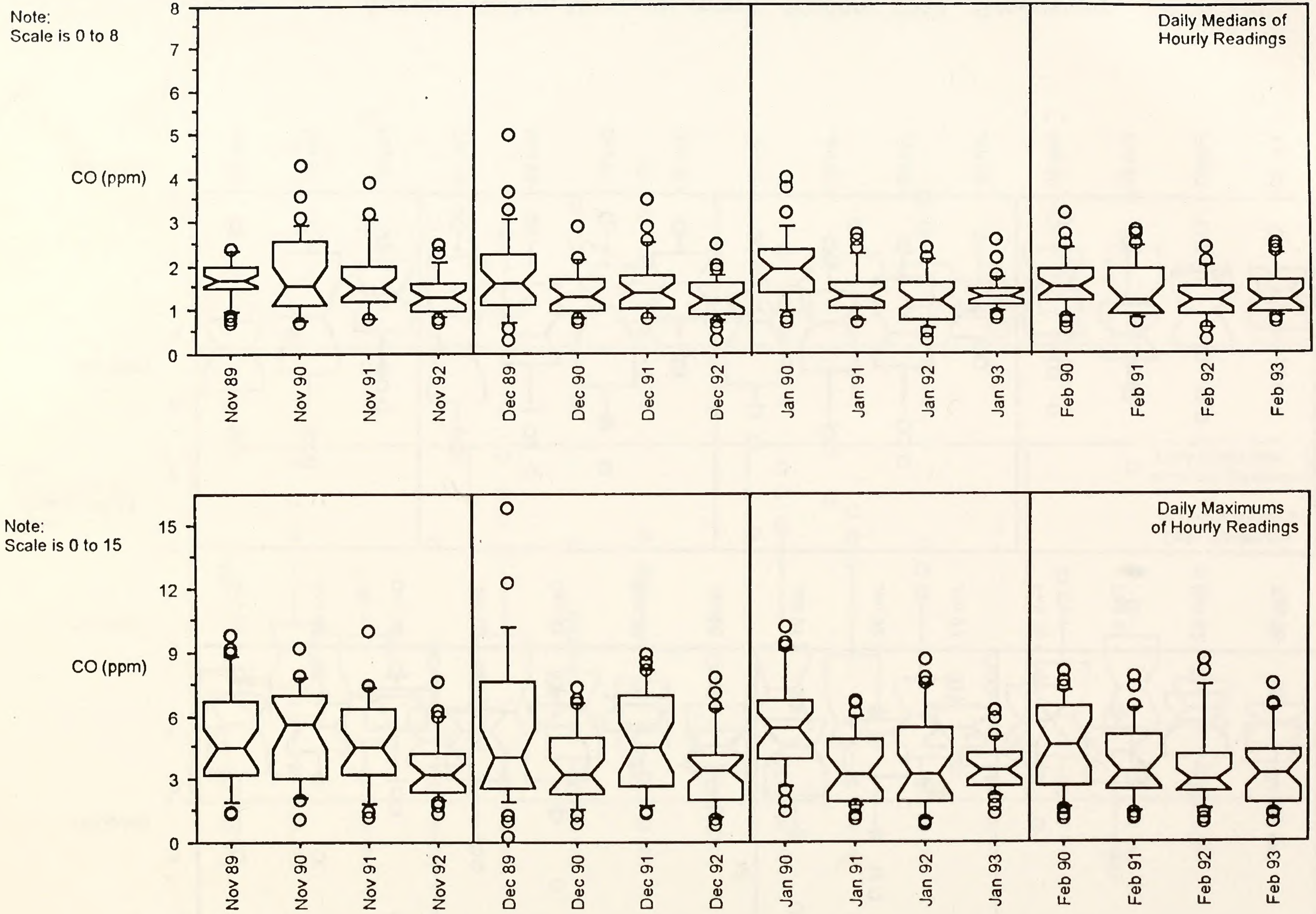
Appendix I.5



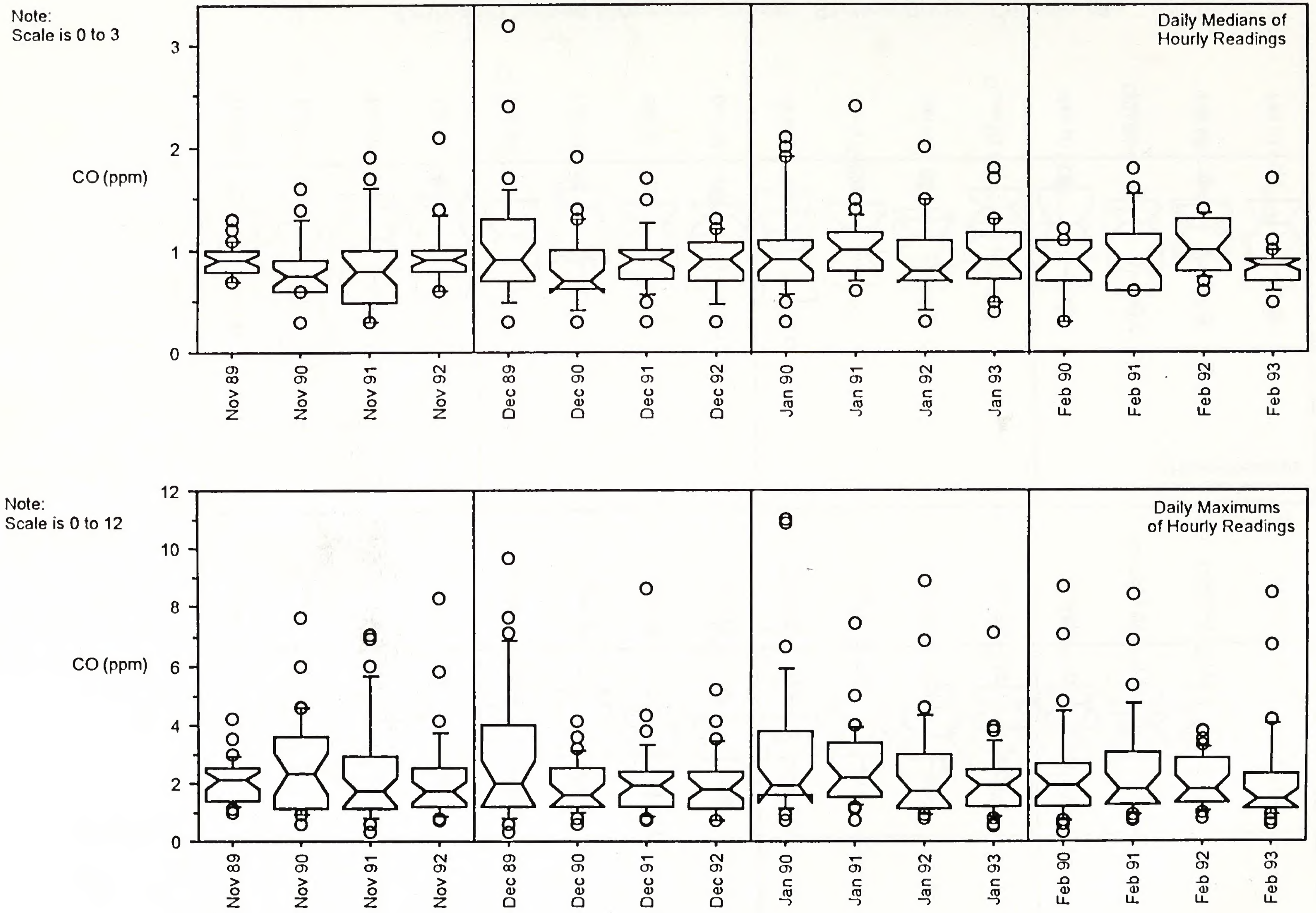
Note:
Scale is 0 to 5

Note:
Scale is 0 to 10

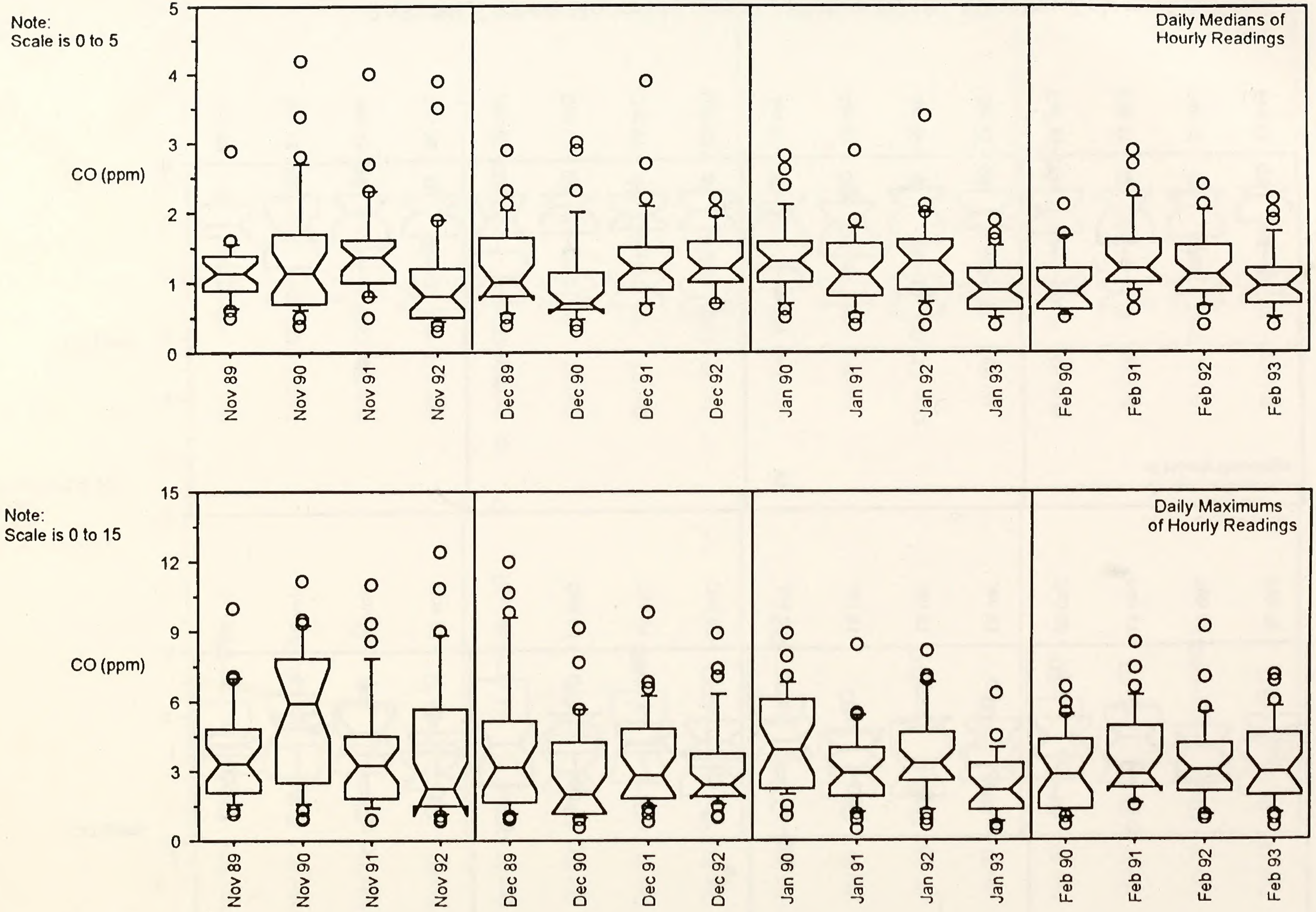
Ambient Carbon Monoxide (ppm) - Stations 1011 - Greensboro
(Grouped by Similar Months Over Different Years)



Ambient Carbon Monoxide (ppm) - Station 0023 - Winston-Salem
(Grouped by Similar Months Over Different Years)



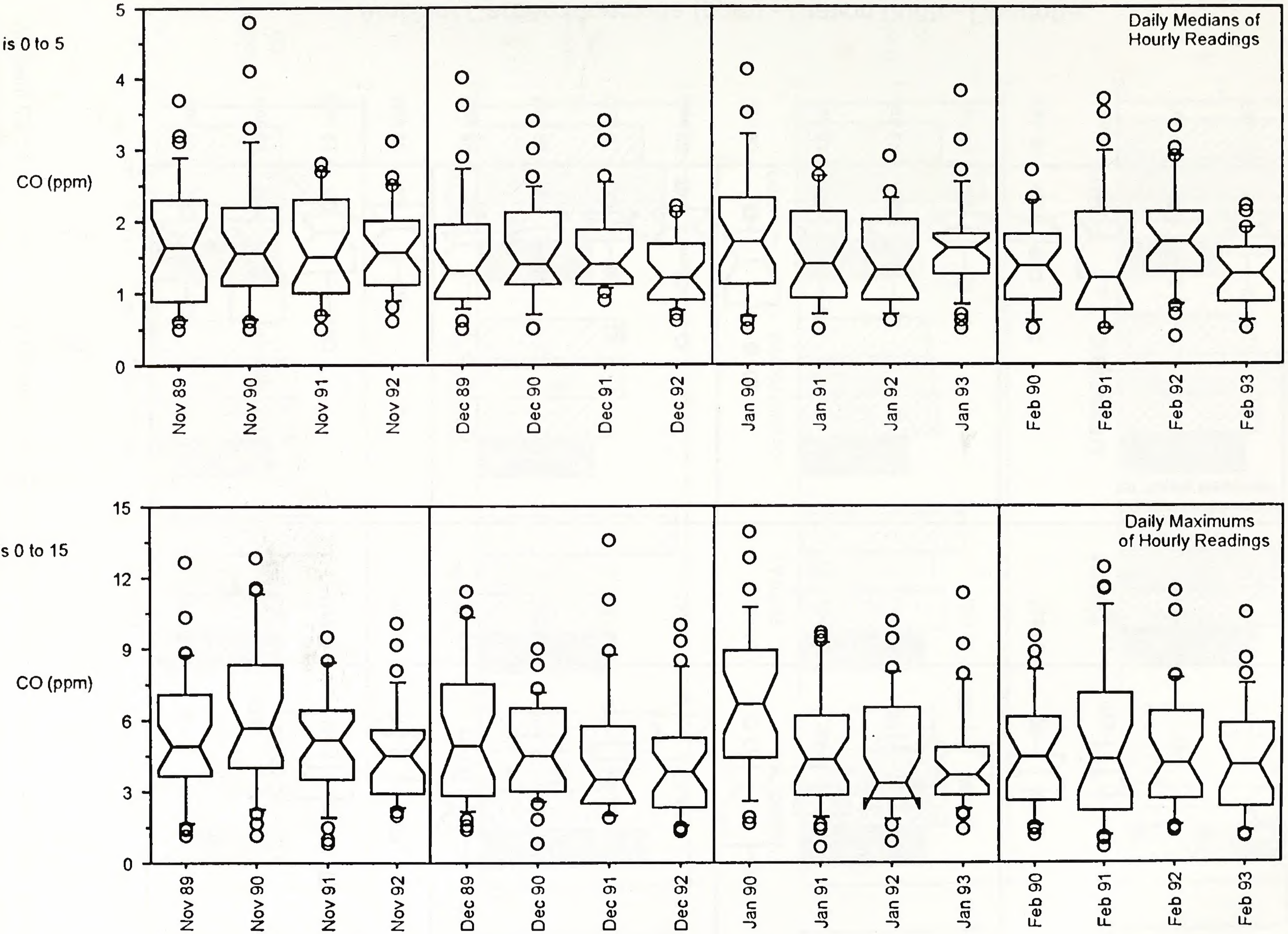
Ambient Carbon Monoxide (ppm) - Station 0018 - Winston-Salem
(Grouped by Similar Months Over Different Years)



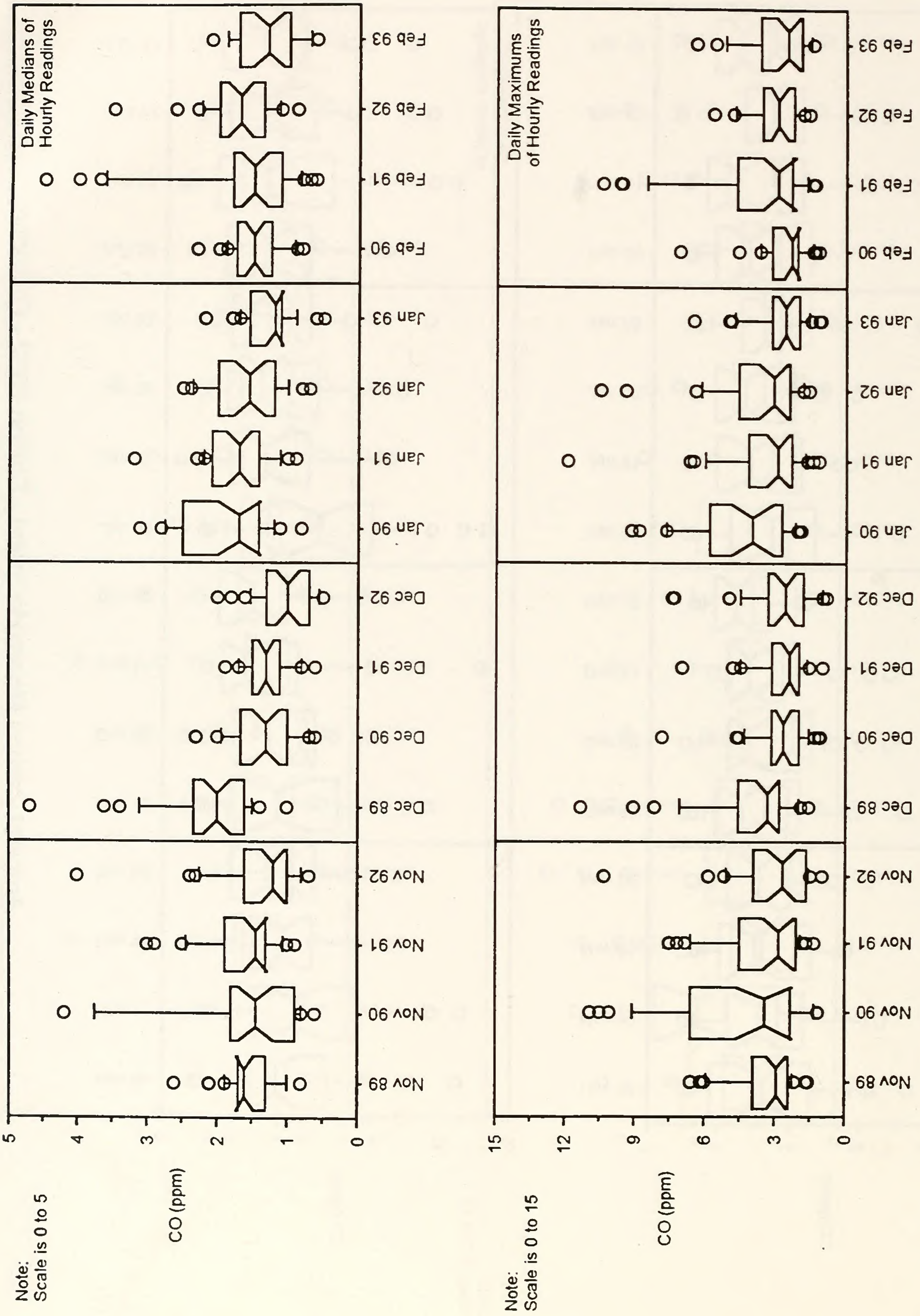
Ambient Carbon Monoxide (ppm) - Station 0007 - Fayetteville
(Grouped by Similar Months Over Different Years)

Note:
Scale is 0 to 5

Note:
Scale is 0 to 15

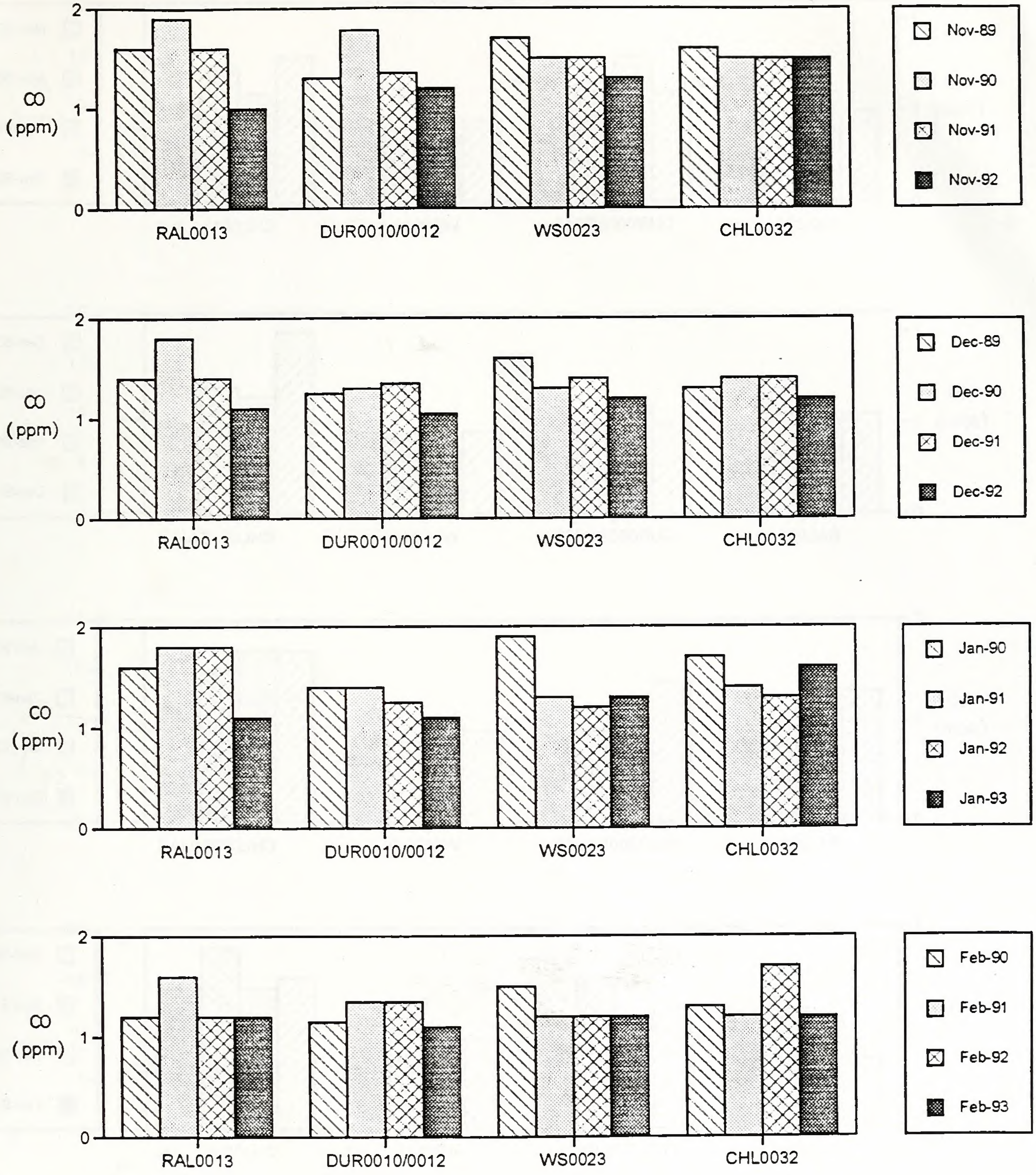


Ambient Carbon Monoxide (ppm) - Station 0032 - Charlotte
(Grouped by Similar Months Over Different Years)

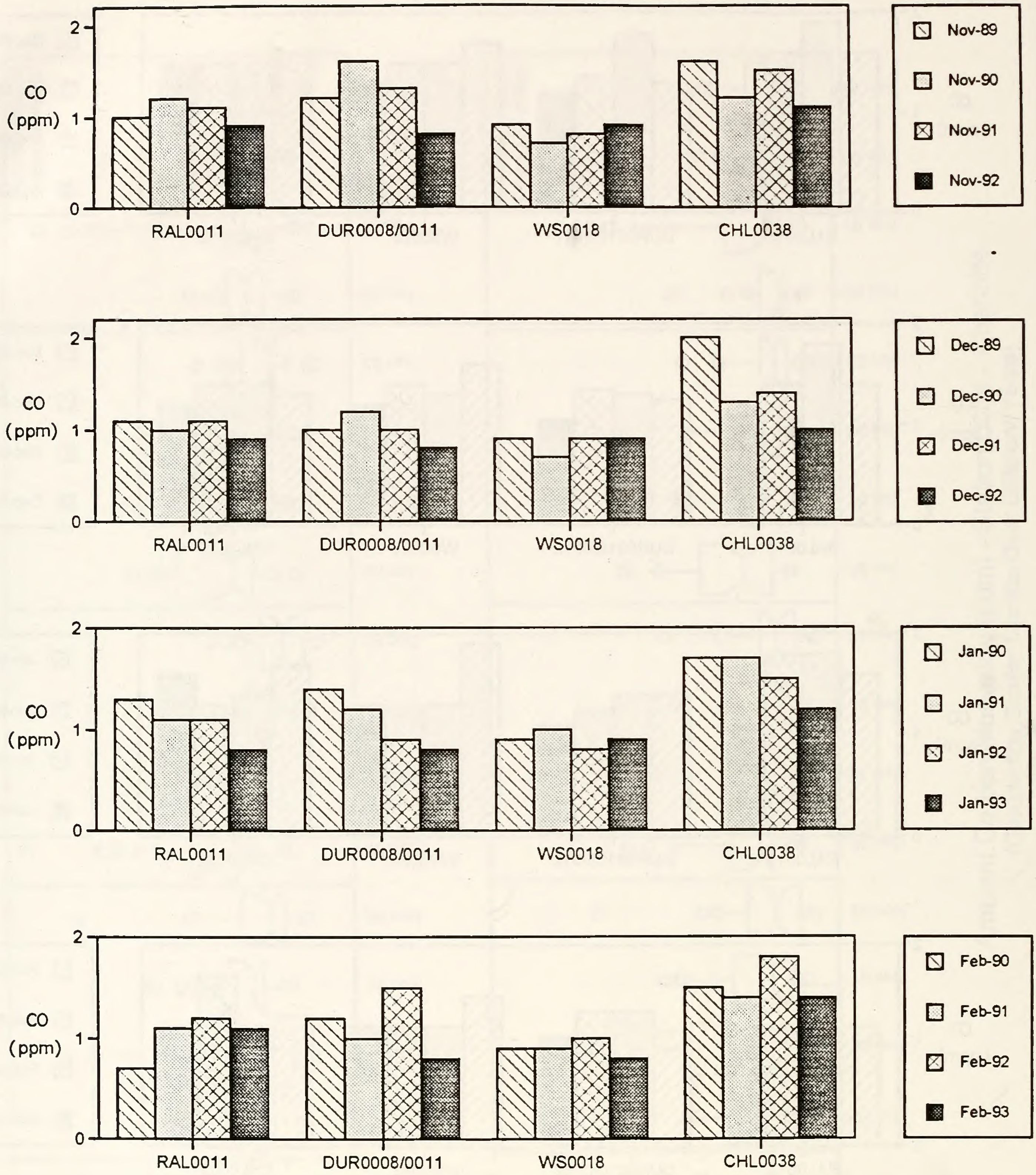


Ambient Carbon Monoxide (ppm) - Station 0038 - Charlotte
(Grouped by Similar Months Over Different Years)

Appendix J.1

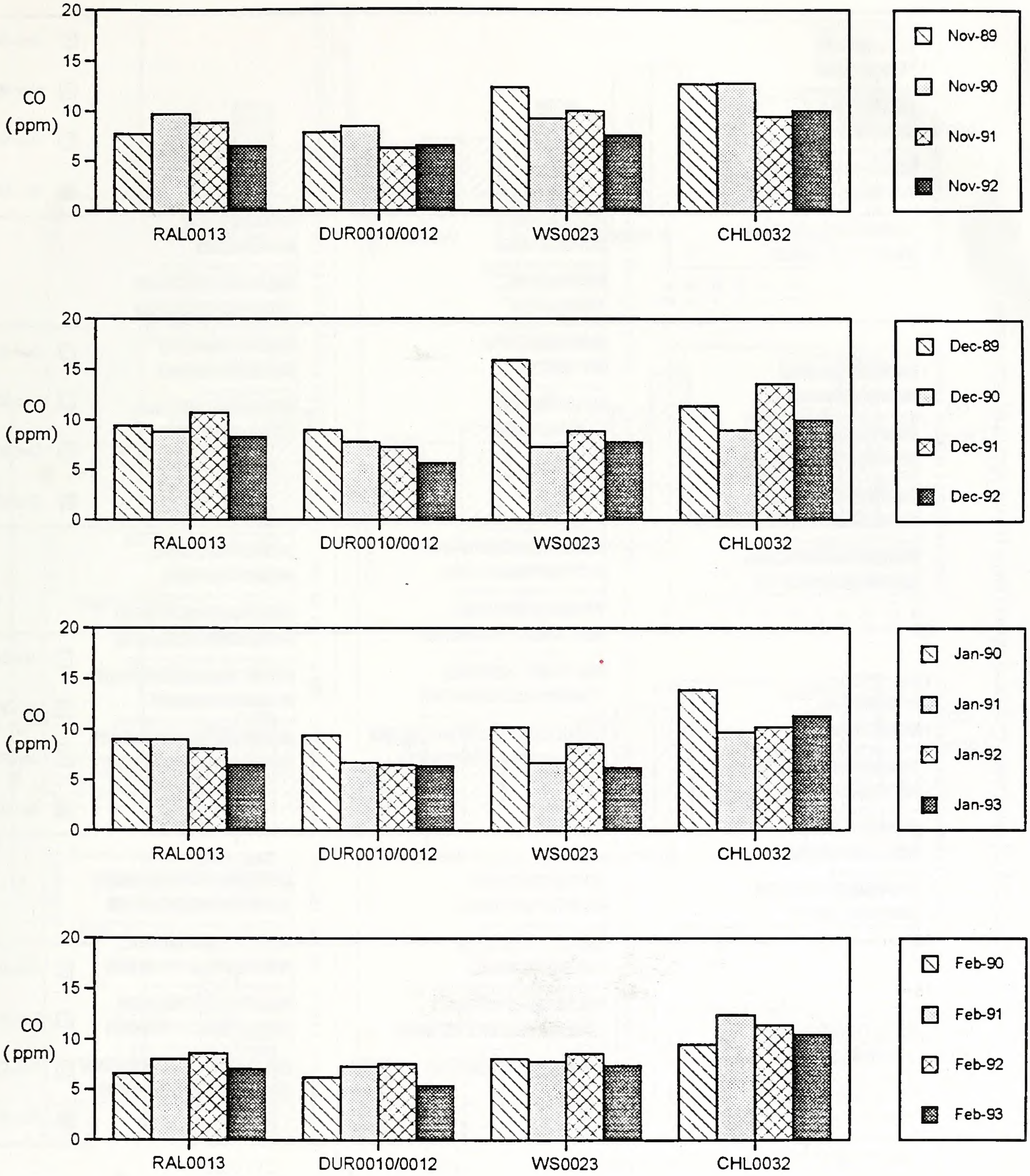


Ambient Carbon Monoxide (ppm) - Monthly Medians of Daily Medians of Hourly Readings - By Sampling Site
Comparison of Stations Located in Oxygenated Fuel Program Area with Stations Outside Participant Area
(RAL0013 DUR0010/0012 WS0023 in Area / CHL0032 Outside Area - All Stations Located Near Shopping Malls)

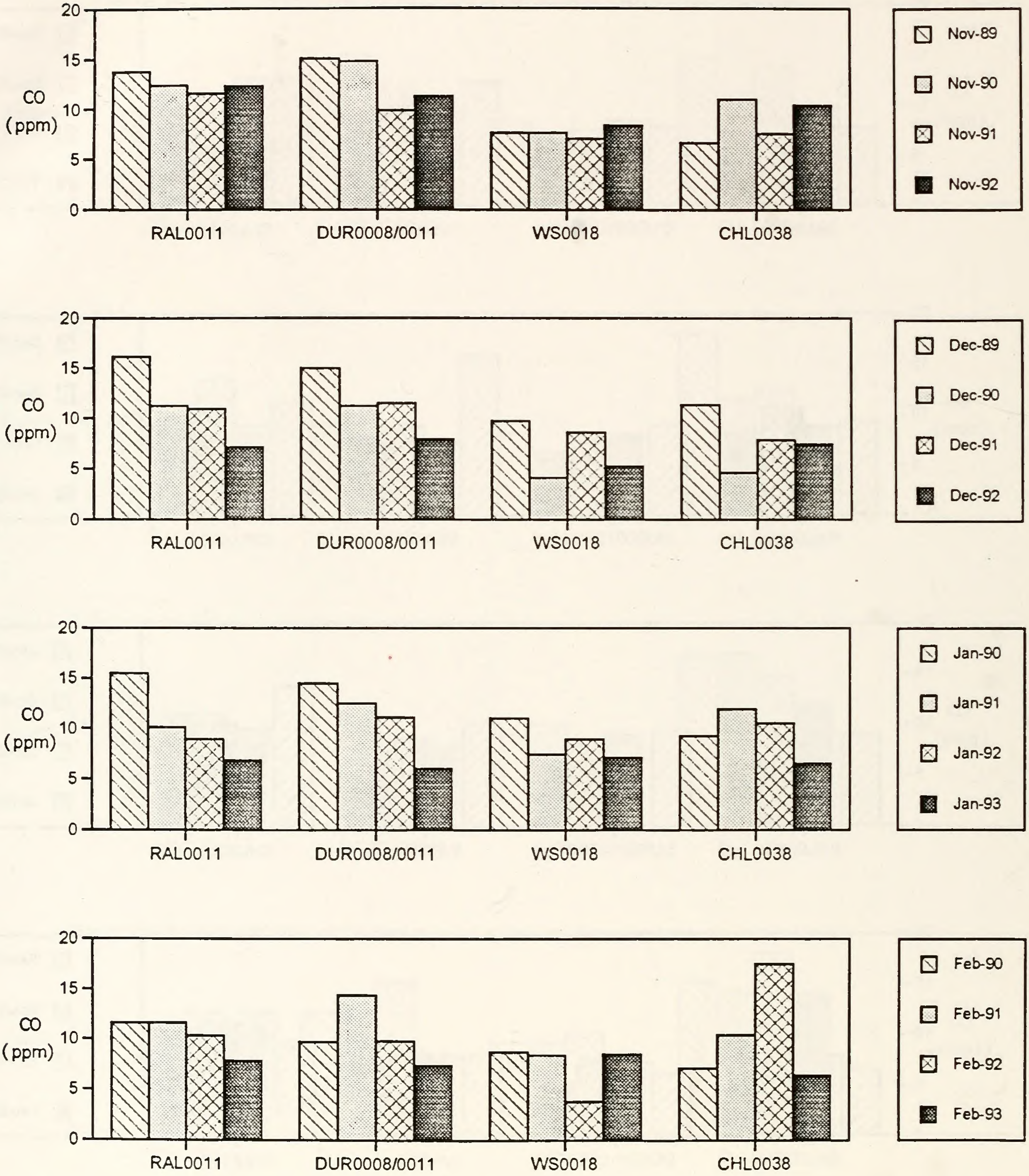


Ambient Carbon Monoxide (ppm) - Monthly Medians of Daily Medians of Hourly Readings - By Sampling Site
Comparison of Stations Located in Oxygenated Fuel Program Area with Stations Outside Participant Area
(RAL0011 DUR0008/0011 WS0018 in Area / CHL0038 Outside Area - All Stations Located Near Downtown Area)

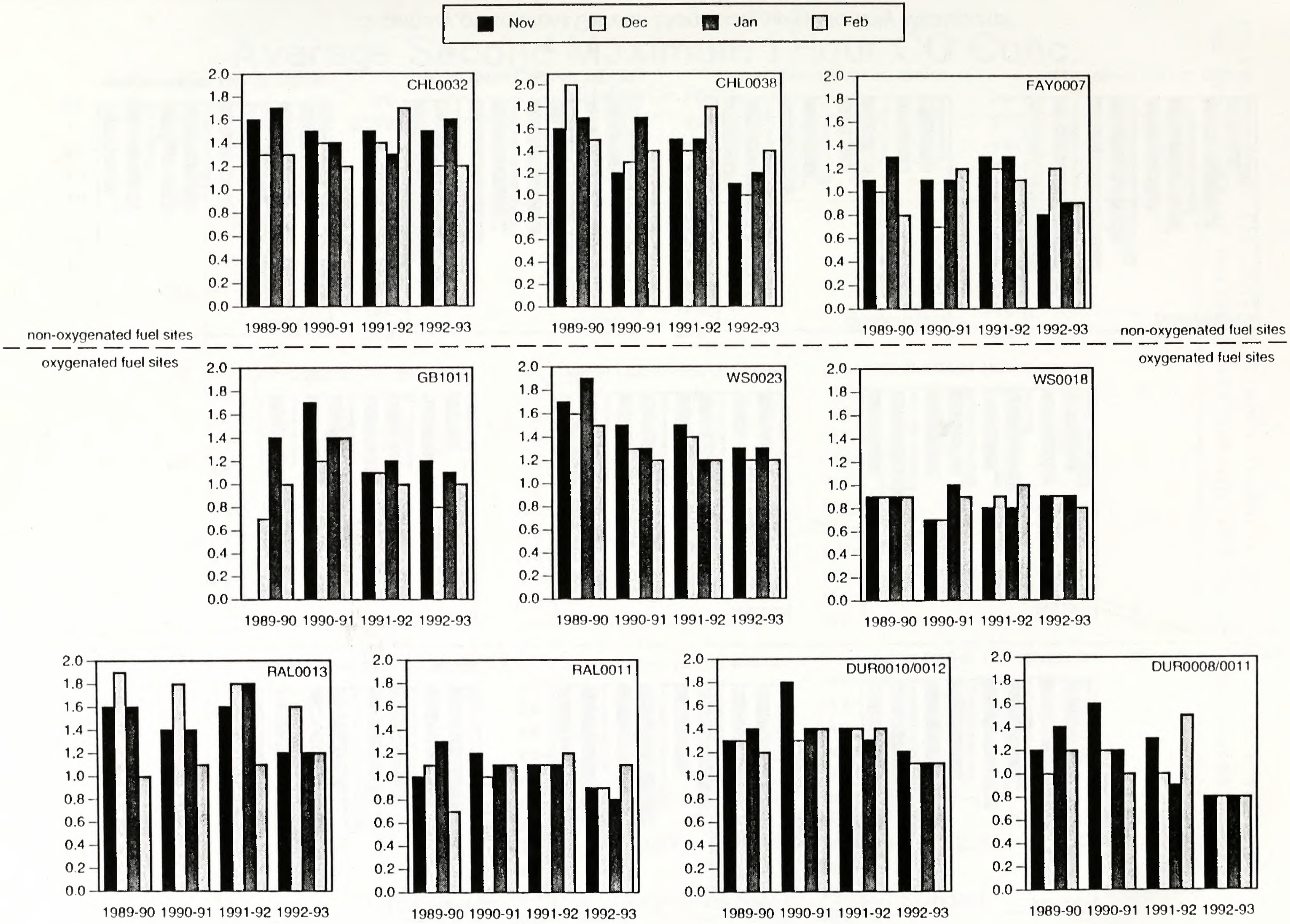
Appendix J.3



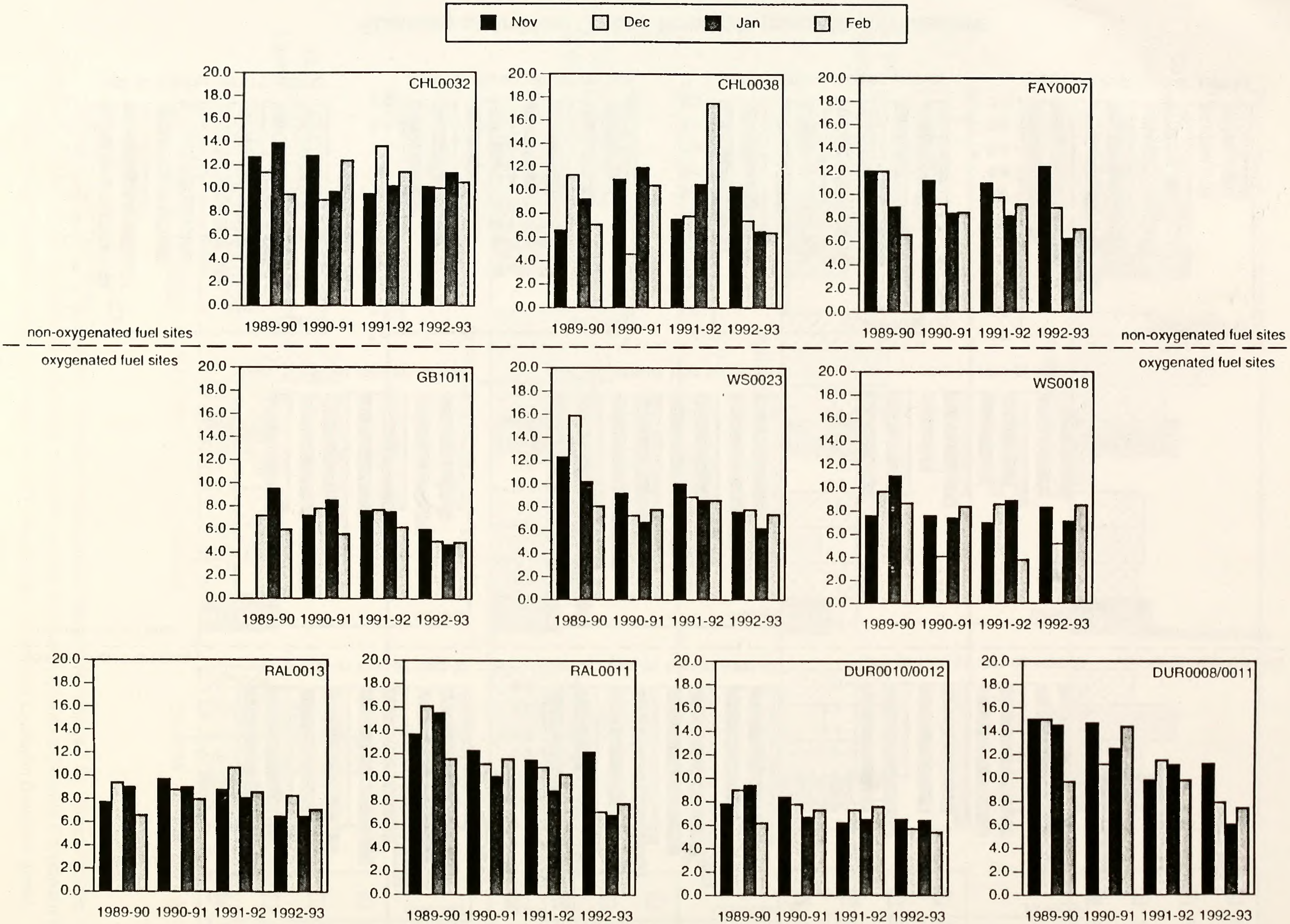
Ambient Carbon Monoxide (ppm) - Monthly Maximums of Hourly Readings - By Sampling Site
Comparison of Stations Located in Oxygenated Fuel Program Area with Stations Outside Participant Area
(RAL0013 DUR0010/0012 WS0023 in Area / CHL0032 Outside Area - All Stations Located Near Shopping Malls)



Ambient Carbon Monoxide (ppm) - Monthly Maximums of Hourly Readings - By Sampling Site
Comparison of Stations Located in Oxygenated Fuel Program Area with Stations Outside Participant Area
(RAL0011 DUR0008/0011 WS0018 in Area / CHL0038 Outside Area - All Stations Located in Downtown Areas)

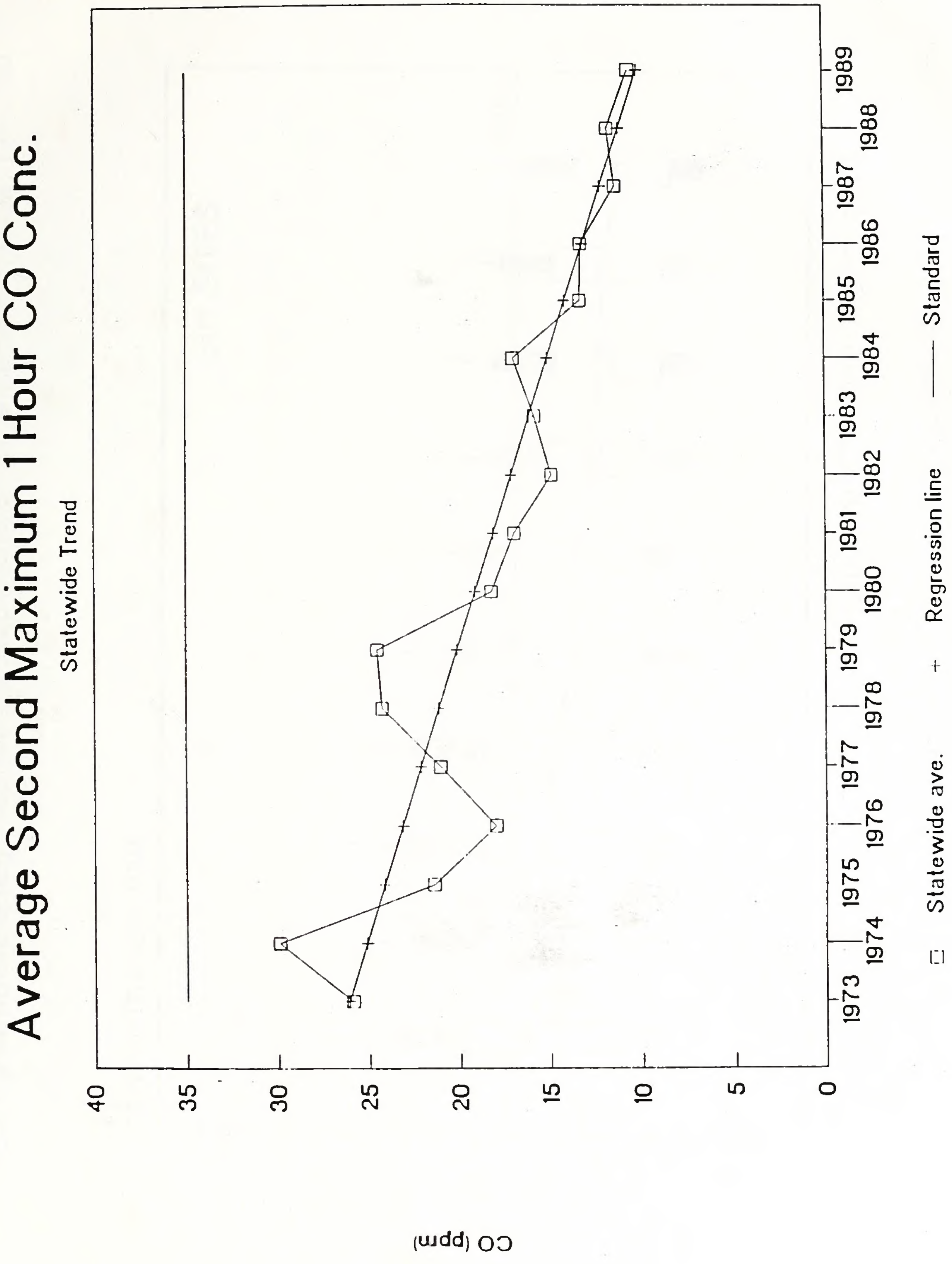


Summary of Ambient Carbon Monoxide (ppm) Monthly Medians

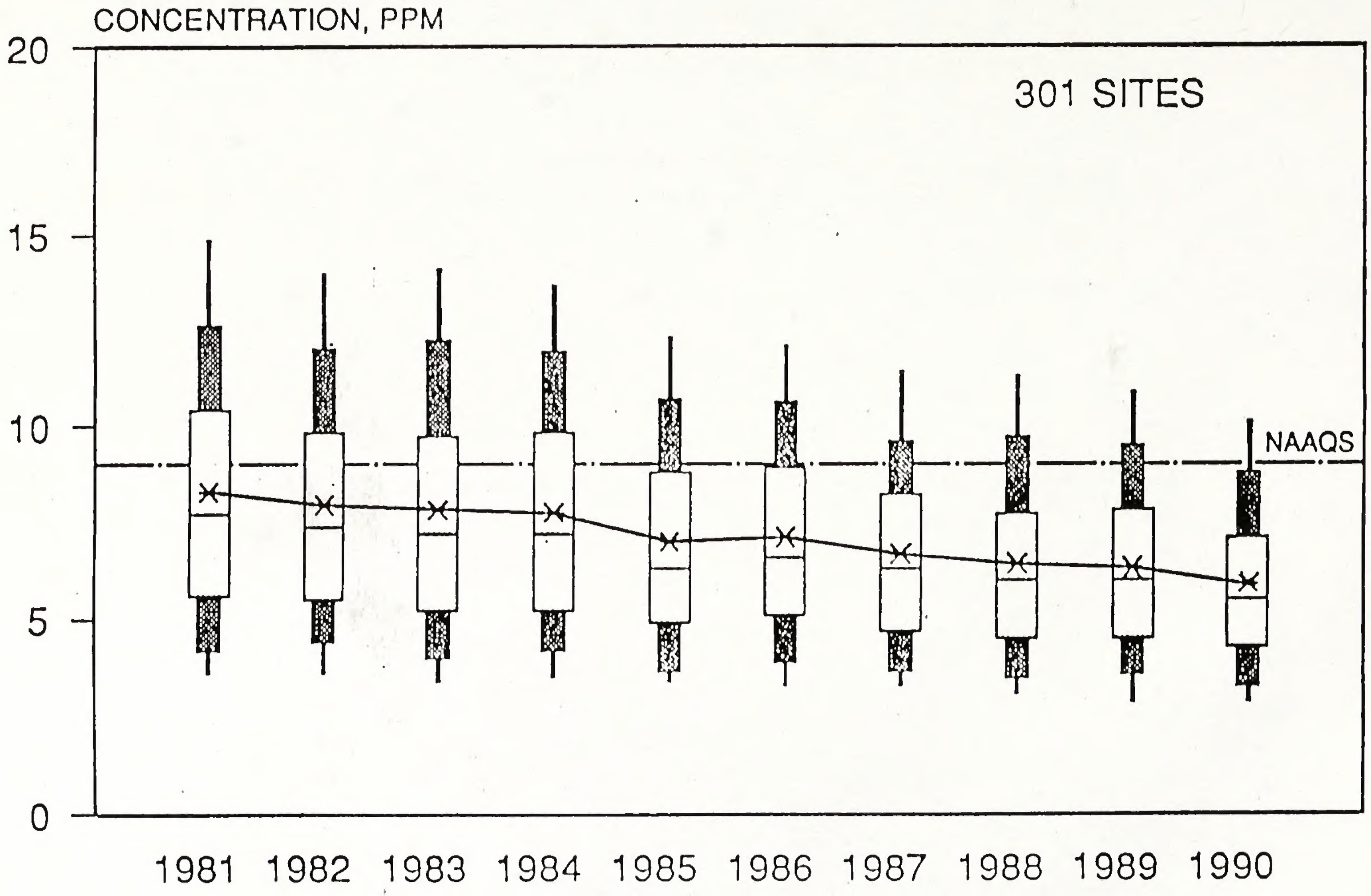


Summary of Ambient Carbon Monoxide (ppm) Monthly Maximums

(from "Ambient Air Quality Trends in North Carolina 1972-1989"
NC Department of Environment, Health, and Natural Resources, 1991)



Second Highest Nonoverlapping 8-hour Average Carbon Monoxide Concentrations at 301 Sites, 1981-1990



(from "National Air Quality and Emission Trends Report, 1990" - US EPA, November 1991)

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